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# SOLAR ENERGY APPLICATIONS IN THE YEMEN ARAB REPUBLIC

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Not the least, I thank the members of my patient family, particularly my wife, for their forbearance during the lengthy process of putting this thesis together.

## GENERAL SUMMARY

It is indeed seldom that a specialised subject can be considered independently. Usually it is allied to and embodied in a systematic sequence of principles, and its field is generally an integral part of a reflection of some broader conception. This is especially true of this thesis, which is concerned with the climatic environmental influences on regional architecture. In the process of evolving the passive solar aspects, theoretical considerations yielded some interesting details and solutions. Examples studied showed a great variety of design principles. Thus as the material grew it suggested an entity - a theme itself.

The intention of this thesis was to clarify some of the underlying principles of passive solar design methods and by doing so, to secure a firm foundation to avoid emotional interpretations. Accordingly, this thesis deals partly with theoretical aspects, and is partly illustrated by architectural examples. The material was divided into four Chapters. In the first, the annual patterns of energy consumption in residential dwellings in the provincial capital cities of the Yemen Arab Republic and their suitability for harnessing solar energy either passively, actively, or both were investigated. Depending upon occupancy and energy-use patterns, as well as according to geographical location, the investigation indicated that the annual fuel consumption per house varied from 16 to 32 GJ. On the assumption that this domestic energy load is satisfied by conventional energy resources, a typical family of five in the Yemen Arab Republic would spent between 29 and 51% of its income on fuel. The prospects for employing passively-gained solar energy appeared promising: in this respect, 70% of all urban residential houses considered have their walls oriented favourably without direct solar radiation being obstructed. Also 80.5% of the flat roofs were free from over-shading at all times, and thus were suitable locations for roof-mounted solar-energy harnessing devices. The second Chapter dealt with solar radiation data, and the processing of these data to arrange them in forms needed for the calculation of process performance.

For this purpose, the diurnal global insolation was measured over a 3-year period with a precision pyranometer at Sana'a University's solar station latitude $15^{O}$N; longitude $44^{O}$E;and 2210 m above sea level. Comparison has been made with predictions obtained from three different empirical models proposed by earlier investigators. Durations of sunshine hours, in addition to geographical latitude and altitude above mean sea level, were the only model inputs required. The calculated values obtained from a modified version of Exell's empirical formulae gave agreement to within $\pm$ 6 per cent with the measured data. The predictions from the regression equation of Page and the relation proposed by Barbaro et.al. agreed to within $\pm$ 10 per cent with the measured solar radiation intensities.

The analysis of the thermal design efficiency of the Yemeni residential dwellings started in Chapter Three, where a simple steady-state mathematical model describing the average daily rate of heat loss through the walls, windows and flat roof of a generalised Yemeni building was developed. From this, a technique was evolved by which designers can predict approximately the transient rate of heat loss via traditionally-employed combinations of indigenous materials, as used in the walls and roof. The principal variable was the ratio of the total glazed area for each storey to the corresponding sum of the surface areas of the solid walls and roof in contact with the ambient environment. The predictions, expressed graphically, enable designers to select the most suitable combination of locally-available indigenous building materials, so that more energy effective dwellings can be built. Because the future of solar-energy applications, in particular the passive applications, depends on the costs of solar energy systems, and the availability of their components at an economic cost, I choose to conclude this thesis with a design method which combined the effects of many design variables as well as the local weather data on the thermal behaviour of buildings incorporating direct-gain or Trombe walls as a south-facing passive heating system. For this purpose, an ambient-energy recuperation factor was developed and correlated with the thermostat-outdoor temperature difference divided by the total amount of solar energy transmitted into the house. This factor was obtained by solving a one-dimensional heat balance equation and it was expressed as a function of the total amount of solar and internal gains, the overall thermal conductance of the house, and the thermal properties of the local building materials. Practically, the design method presented in the last chapter of this thesis, enables designers to estimate the solar contribution to the building heating requirements, the amount of heat that is in excess of the house load, and the variation of the internal house temperature with respect to time. It also provides a number of graphs,by which designers can choose the appropriate passive heating system parameters for tropical climates and thereby design their system to be both cost effective and thermally comfortable.

In short,this thesis begins with an introductory chapter describing the patterns of energy usage in the urban residential houses of the Yemen Arab Republic as well as their suitability for solar energy applications. The remaining chapters deal with the steps of the passive design process. As building designs progress, the amount of required detail increases. This is reflected by the size of the later chapters and the amount of information contained in each. It may, therefore, appear to a person reading through this thesis that the presentation is at times repetitive. However, the difference between one chapter and the next lies in the level of detail presented and not in the subject matter. Finally, it is the wish of the author to see the results of this work translated into physical reality.

# CHAPTER ONE

## ENERGY USED DOMESTICALLY IN THE YEMEN ARAB REPUBLIC

# GLOSSARY

In the context of the Yemen Arab Republic, a city is typically an urban region with a typical population of approximately 45 thousand people; the urban region being a mixture of residential houses and industrial premises.

# NOMENCLATURE

| | | |
|---|---|---|
| $A$ | Considered room's floor area | $m^2$ |
| $C$ | Per capita expenditure on fuel, as defined in equation (16) | U.S.$ |
| $C_p$ | Specific heat of water (= 4190 $kg^{-1}$ $^\circ C^{-1}$) | |
| $dd_h$ | Degree-days for heating, defined by equation (12), with respect to a reference temperature of 18.3°C | °C-day |
| $f_\ell$ | Fraction of the 24-hour day, during which artificial illumination was employed in the considered rooms of the house | |
| $F_h$ | Proportion, supplied by natural gas, of the energy used for cooking: deduced from the survey data - see Table 2(iv) | |
| $f_w$ | Fraction of the 24-hour day, during which hot water was being used by the occupants of the household | |
| $I$ | Per capita income of the head of the typical family: deduced from the survey data - see Table 2(v) | U.S.$. |
| $K$ | Constant characteristic of the type of household; = $N_p\ L\ f_w\ \rho\ C_p$ - see Table 2(iii) | $J^\circ C^{-1} day^{-1}$ $(person)^{-1}$ |
| $L$ | Average amount of <u>hot</u> water each person used per day | $m^3 day^{-1}$ |
| $n_{fjm}, n_{tjm}$ | Numbers of fluorescent and tungsten lamps respectively used to illuminate the rooms in the considered house | |

NOMENCLATURE (cont)

| | | |
|---|---|---|
| $n_h$ | Total number of houses in a given geographical location | |
| $n_j$ | Total number of rooms in the considered house with a floor area in the jth category: j = 1, 2, 3 or 4 | |
| $n_{j\ell}$ | Number of fluorescent or tungsten lamps used to illuminate the rooms, which, for the considered house, were in the jth category with respect to floor area | |
| $N$ | Number of days in the considered calendar month | |
| $N_p$ | Number of occupants in the house: obtained from an analysis of the survey data - see Table 2 (iii) | |
| $P_f, P_t$ | Rated powers respectively of the most commonly used fluorescent and tungsten lamps in the considered house | W |
| $P_i$ | Rated power of the ith appliance used in the considered house | W |
| $P_k$ | Power provided by a kerosene lamp, when used for illuminating a room in the considered house | W |
| $P_n$ | Total expenditure paid for natural gas by the house owner per calendar month: deduced from an analysis of the survey data - see Table 2(iv) | U.S.$ (month)$^{-1}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\bar{P}_T$ | Calculated <u>total</u> power of the lamps used to illuminate the various rooms in the house - see Table 2(ii) | W |
| $P_{TF}, P_{Tt}$ | <u>Total</u> powers of the fluorescent or tungsten lamps respectively which are used to illuminate the rooms of all the houses located in the considered geographical region - see equations (4) and (5) respectively | W |
| $\bar{P}_{Tft}$ | <u>Total</u> power of the fluorescent and tungsten lamps used to illuminate the rooms of all the houses located in the considered geographical region - see equation (6) | W |
| $Q_c$ | Per capita consumption of energy, as defined by equation (15) | $MJ(person)^{-1}$ |
| $\dot{Q}_{ap}$ | Energy load due to applicances, as defined by equation (1) | Whr $day^{-1}$ |
| $\dot{Q}_{co}$ | Cooking load, as defined by equation (9) | Whr $day^{-1}$ |
| $\dot{Q}_{hh}, \dot{Q}_{hc}$ | Heating and cooling loads respectively for the considered house, as defined by equations (11) and (14) | Whr $day^{-1}$ |
| $\dot{Q}_L$ | Lighting load, as defined by equation (2) | Whr $day^{-1}$ |
| $\dot{Q}_T$ | <u>Total</u> energy load of the house - see Fig. 7 | Whr $day^{-1}$ |
| $\dot{Q}_{wh}$ | Water-heating load, as defined by equation (8) | Whr $day^{-1}$ |
| $\bar{T}_a$ | Annual average daily ambient temperature, as listed in Table 2(v) | $^{o}C$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $(UA)_h$ | Building's overall energy loss coefficient multiplied by the house's external total surface area, as defined by equation (13) | $W\ K^{-1}$ |
| $(UA)_w, (UA)_r, (UA)_g$ | Heat loss coefficient multiplied by the appropriate area for walls, roof and floor and glazed elements respectively | $W\ K^{-1}$ |
| $\dot{V}$ | Volume rate (at atmospheric pressure) of air infiltration into (or ventilation from) the house | $m^3 hr^{-1}$ |
| $\Delta t$ | Average duration per day during which artificial light was switched on in the considered room of the house | sec $day^{-1}$ |
| $\Delta t_i$ | Operating time for the ith appliance | sec $day^{-1}$ |
| $\Delta t_s$ | Theoretical operating period, as defined by equation (3) | sec $day^{-1}$ |
| $\eta_o, \eta_i$ | Efficiencies for the gas oven and the ith appliance respectively | |
| $\rho$ | Density of water | kg $m^{-3}$ |
| $\phi$ | Percentage of the household's income spent on fuel: an expression for which is given by equation (17) | % |

<u>Suffixes</u>

| | |
|---|---|
| a | Ambient environment |
| ap | Appliance |
| c | Consumption |

## NOMENCLATURE (cont)

| | |
|---|---|
| co | Cooking |
| f | Fluorescent |
| g | Glazing |
| h | House |
| hc | House cooling |
| hh | House heating |
| i | Integer, which takes values from unity to n, indicating the types of appliance used in the house |
| j | Integer, which takes values from unity to 4, so designating the sizes of the floor for the rooms of the considered house |
| k | Kerosene |
| $\ell$ | Lamp |
| L | Artificial light |
| m | Integer which refers to the way in which the various rooms in the house are illuminated: it is defined, for $j > 2$, by $m = j-1$, see equation (6) |
| n | Natural gas |
| o | Oven |
| p | Person |
| r | Roof |
| t | Tungsten |
| T | Total |
| w | water |
| wh | Water heating |

# CHAPTER 1

## ENERGY USED DOMESTICALLY IN THE YEMEN ARAB REPUBLIC

### THE AIMS

Buildings are major consumers of energy in the Yemen Arab Republic (YAR). Approximately 90% of the total electricity generated and 10% of the total imported oil are expended upon heating, lighting and other building services {1}. As part of an investigation into 'passive solar gain and housing design', a survey of the annual energy demands from the existing urban detached housing stock, located in the capital cities of the YAR, was carried out during the period April-to-December 1982. The survey's prime aim was to estimate the total number of city houses suitable for harnessing solar energy, either passively, actively or both. Specifically the objectives of the survey can be summarised as follows:-

- To determine the annual consumption patterns for the various fuels in the YAR
- To provide rational criteria for assessing passive solar designs with emphases on:-
    - a) choice of appropriate wall and roof materials;
    - b) the ratio of glazed area to the total house floor area;
    - c) orientation and obstruction with respect to the solar insolation; and
    - d) domestic energy-requirements for heating and cooling.
- To rank, according to financial viability, existing and prospective solar-energy applications in the Yemeni domestic sector.

## SURVEY METHODOLOGY, SOURCES OF ERRORS AND SAMPLING TECHNIQUE

### Classification Scheme

Urban detached houses, which represent 70% {2} of the housing stock in the YAR, were considered in this survey. According to their annual fuel consumptions, i.e. the types and quantities of energy employed for space heating and cooling, water heating, lighting, cooking and for other appliances, the urban houses can be classified into two major energy-consuming categories (see Fig. 1).

Zone 1: This includes all urban houses, whose annual consumptions range from 16 to 25.6 GJ per house. Geographically, this category includes houses from Maarib and Al-Beida in the east, and from Ibb and Dhamar in the interior Ibb plain to Al-Mahweet and Hajjah in the west.

Zone 11: This comprises houses from Taiz in the south and Sana'a in the interior Ibb plain to Al-Hodiedah in the west. The annual consumption, in this category, ranges from 21 to 32 GJ per house.

For comparison purposes, the corresponding average fuel consumption per house in the United Kingdom was 46.5 GJ {3} .

To permit generalisations to emerge from the gathered data, we grouped the urban houses located in these zones as follows:-

Group 1: Those built with external walls for each storey of the same construction material, e.g. stone, mud, <u>or</u> red brick.

Group 11: Those in which each house had different masonary materials for the external walls according to the storey. Two types of vernacular built forms can be discerned in this group. These are:- (i) those dwellings with a first storey of stone and all subsequent storeys built of less dense materials {4}, and (ii) those with a concrete first storey, but

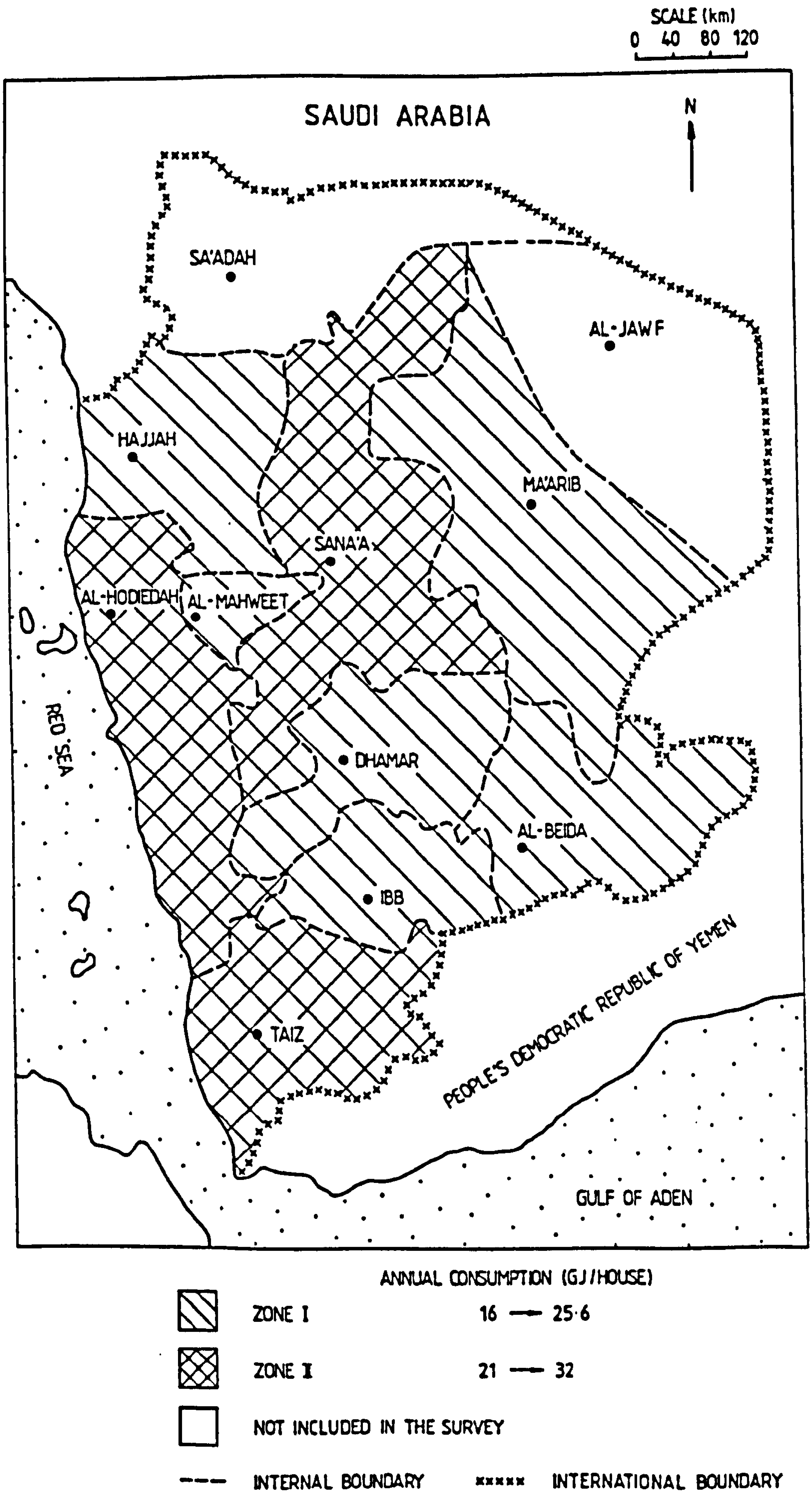



FIG. 1 THE TWO CONSIDERED DOMESTIC ENERGY CONSUMPTION ZONES FOR URBAN HOUSES IN THE YEMEN ARAB REPUBLIC.

with upper storeys built of either less or more dense materials. These forms are assigned the designations of vernacular house types (i) and (ii) respectively in the subsequent analysis.

## Survey Sample

The distribution of the sample of dwellings surveyed, see Table 1, was dictated by factors such as:-

- Population density and size of individual regions.
- Technical complexity of the data to be collected.
- Availability of qualified coordinators for the task. Their functions were to distribute the questionnaires, to explain to the prospective respondents the meanings of the various technical terms used in the survey questions, and to collect the completed forms. The difficulties involved in finding such capable coordinators limited severely the number of the distributed questionnaires.
- Educational level of the people being questioned, i.e. the respondents capabilities with respect to understanding the technical terms, units, dimensions, rated powers of the household electric equipment, as well as the details of the construction and materials of their house walls, roofs, and floors, necessary to complete the answers to the questionnaire properly.

Because of these factors and to guarantee the completion of the survey as required, we limited the random sampling to the capital cities of each region - see Fig. 1.

## The Questionnaire

Various preliminary versions of the questionnaire were composed and tested on a small, but representative, sample of respondents with respect to such factors as:-

TABLE 1

QUESTIONNAIRE DISTRIBUTION AND RETURNS

| REGION'S CAPITAL | NUMBER OF DISTRIBUTED QUESTIONNAIRES | NUMBER OF REPLIES RETURNED WITH AMBIGUOUS OR INSUFFICIENT INFORMATION | NET NUMBER OF PROCESSED REPLIES |
|---|---|---|---|
| SANA'A | 1000 | 60 | 940 |
| TAIZ | 600 | 55 | 545 |
| AL-HODIEDAH | 300 | 23 | 277 |
| IBB | 50 | 0 | 50 |
| DHAMAR | 50 | 0 | 50 |
| HAJJAH | 50 | 15 | 35 |
| AL-BEIDA | 50 | 10 | 40 |
| AL-MAHWEET | 50 | 10 | 40 |
| MA'ARIB | 50 | 10 | 40 |
| TOTAL | 2200 | 183 | 2017 |
| PROPORTION OF TOTAL | 100% | 8% | 92% |

- Technical complexity. To facilitate understanding, the use of locally-employed (in addition to SI) units was found to be necessary. For example, the "Tankah" (which is equivalent to twenty litres) was employed as the basic unit of measurement for water consumption.
- Availability of the required data, such as the monthly bills for electricity, gas and water consumptions; monthly income; amounts of money paid monthly for purchasing wood, animal waste and agricultural residues; rated powers of the applicances used in the house and other information which related to:- the location; floor, wall, and roof areas; number of occupants; and patterns of energy use within the houses.
- Ease of interpretation of the presented questions. Normally this required the use of the standard version of the Arabic language. However, for some questions, it was difficult to express exactly what was needed using standard Arabic, and therefore the local dialect, in addition to standard Arabic, was employed.
- Acceptability of devoting the time required ($\sim$ 30 minutes) for "filling up" the questionnaire.

The finally-devised version of the questionnaire was also based partially on the experiences gained from previous surveys, carried out by the Central Planning Organisation and by Sana'a University {5,6}. Eventually, it evolved to comprise a total of twenty-two questions (each consisting of three to six parts), and these were divided into three main sections in the questionnaire. In the first section, the survey sought the geographical location of the house, the number of family members normally living in it and a technical description of the dwelling. In the second section, the questions concerned the types of energy supplies employed in the house and their respective applications, rates of consumption and running costs incurred. The final section was intended to collect information about water - its supply systems, hot and cool water consumption rates, and the daily usage patterns. This section also included a question about the ranking of low-temperature (i.e. $< 80^{\circ}C$) solar-energy applications according to their priorities in both cities and villages. In order to reduce the possibilities of misunderstandings, ambiguities and misinterpretations the questions were chosen as far as feasible to elicit either a 'yes' or 'no' answer, involve completing a sentence, or require the respondent to choose one of the supplied alternative answers.

Sources of Misunderstanding and Difficulty

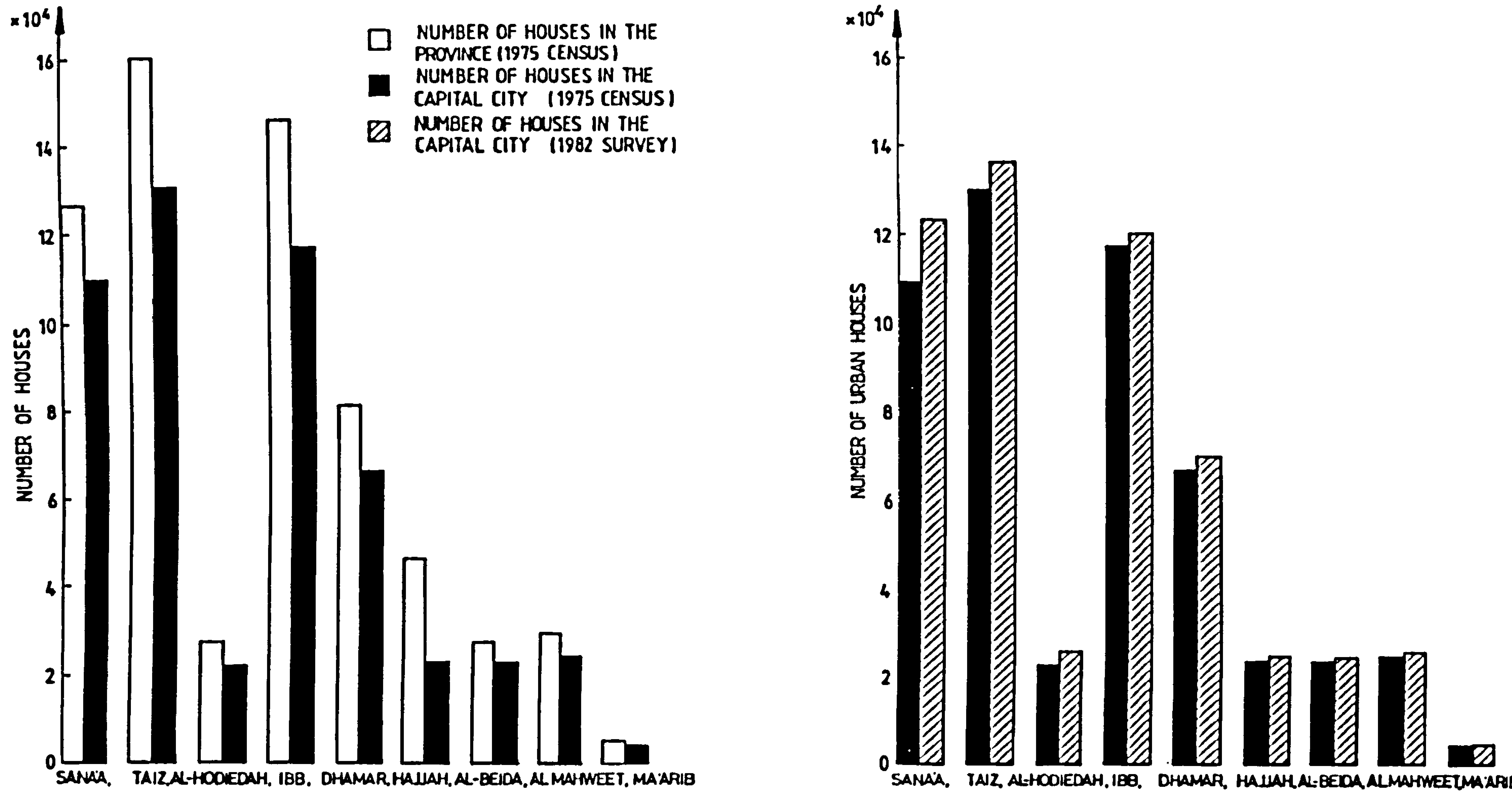
The most obvious ambiguities and problems concerning the printed questions were remedied and corrected after discussion of the answers with the survey coordinators. However, further difficulties were discovered during the check for reasonableness: these were partially overcome after the data had been analysed by computer. Despite these precautions, some forms were not completed according to the printed instructions or not received in time for the analysis to be undertaken: this reduced the number of processed forms by 8%. The answers from the remaining 92% of the distributed forms were analysed in detail. Errors in data handling arose in the coding of the reports and data punching, but these were reduced by three successive checks.

HOUSING STATISTICS (see Fig. 2)

According to the 1975 census {2} there were, excluding the Sa'adah and Al-Jawf provinces, ∿ 664 thousand houses in the YAR distributed as shown in Fig. 2(a): 78.9% of the total housing stock in December 1975 compared with 85% in December 1982 was located in the capital cities considered by this survey. This is because the recent urban development in the YAR occurred predominantly in the provincial capital cities. Fig. 2(b) shows the distribution of the urban houses as compared with that of 1975.

The data summarised in Fig. 3 were derived by interpreting the 1975 figures, adapted for 1982, together with the regional distribution of the building materials as indicated by the answers to the questionnaire.

To apply the gathered data to the whole housing stock located in the capital cities of each province, a weighting procedure was used. The weighting factor for each house was defined as the ratio of the number of houses represented by this particular type of house to the total




(a) DISTRIBUTION OF THE HOUSES AS RECORDED BY THE 1975 CENSUS.

(b) DISTRIBUTION OF HOUSES LOCATED IN THE CAPITAL CITIES AS DEC. 1975 AND DEC. 1982.

FIG. 2 DISTRIBUTION OF DWELLINGS IN THE YEMEN ARAB REPUBLIC (ACCORDING TO THE 1975 CENSUS AND 1982 ENERGY SURVEY).

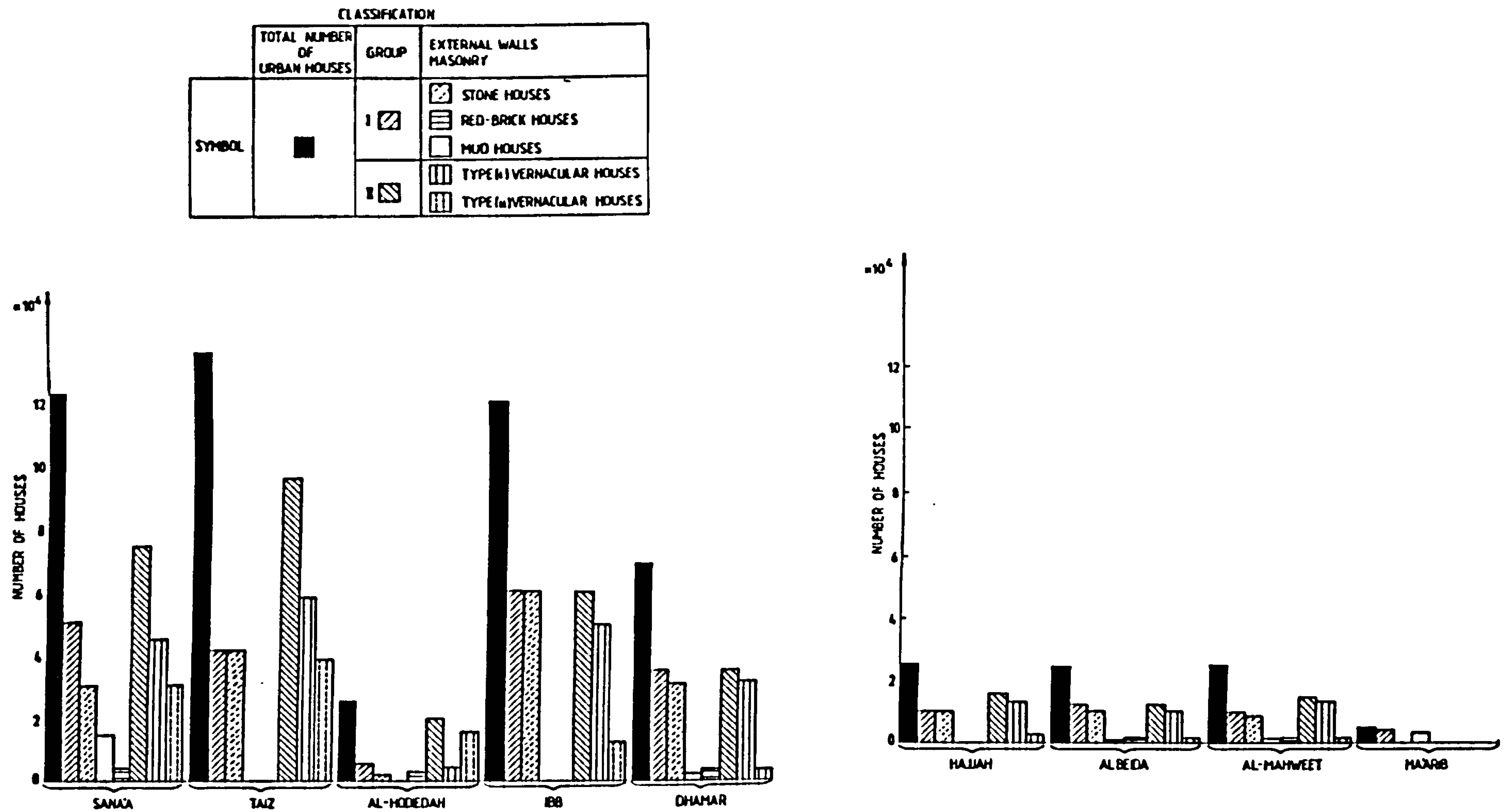



FIG. 3. REGIONAL DISTRIBUTIONS OF URBAN RESIDENTIAL HOUSES ACCORDING TO THEIR EXTERNAL WALLS IN THE YEMEN ARAB REPUBLIC.

number of houses in that province. The magnitude of the weighting factor depended on the number of houses of that type, and their geographical location. Fig. 4 shows the results of the weighting procedure adopted here. The representations for mud and red-brick houses were inaccurate due to the failure to return, in time for processing, all the forms sent to Sa'adah and Al-Jawf provinces, where these two building materials are extensively used {7}. Based on the total number of houses in each group, the results were representative of approximately 80% of the total housing stock. Therefore, it is possible to assume that the conclusions with respect to the prospects for the use of solar energy in urban houses may, with reasonable confidence, be taken as a worthwhile indication of what applies for the whole country.

## PROSPECTS FOR PASSIVE SOLAR-ENERGY APPLICATIONS WITH RESPECT TO YEMENI HOUSING

The most important factors influencing the prospects for harnessing solar energy are the house orientation and the blocking of solar energy by obstructions. In this context, an analysis of the answers to the present survey questions showed that 70% of all urban houses assessed have their walls oriented favourably, with no obstructions inhibiting direct solar gains. In the analysis of the effects of obstructions in intercepting the insolation and so preventing it reaching the walls of the surveyed dwellings, all the direct solar energy incident on a particular wall was assumed to be harnessable: that is in effect, the amount, for example reflected away by the considered walls was equal to that received by reflected solar radiation from neighbouring house walls. The detailed analyses indicated that 30% of these well-oriented walls were free from all obstructions: a further 40% suffered from obstructions which caused only a 10% reduction in the intensity of the direct solar energy striking the house walls. The effects of obstructions with respect to insolation that would otherwise be received by the walls were considerable among the remaining 30% of city houses represented in this survey: 16.5% lose more than 20% of the theoretically-available direct solar insolation falling on the house walls.

In the Yemen, all roofs are flat and almost horizontal: 82.5% of all roofs in the sample were free from obstructions to direct solar

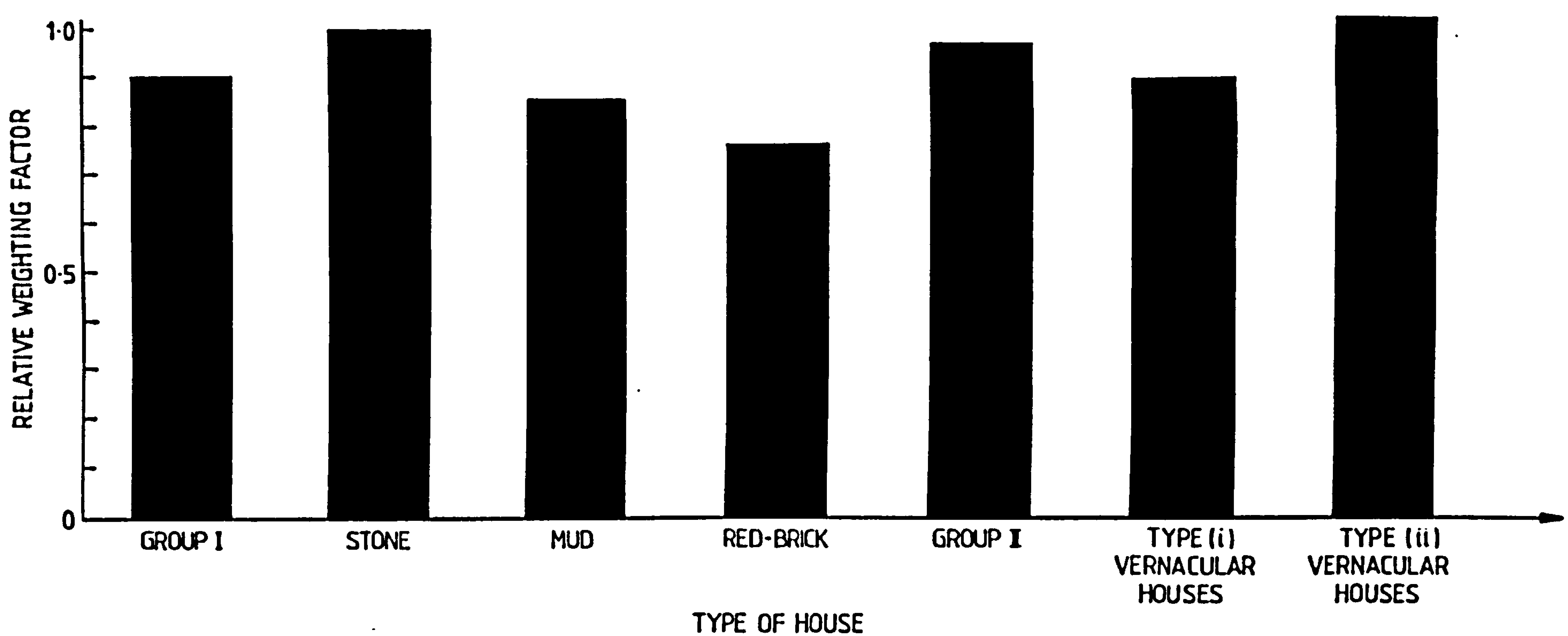



FIG. 4. ANALYSIS OF THE URBAN RESIDENTIAL HOUSING STOCK LOCATED IN THE CAPITAL CITIES OF THE YEMEN ARAB REPUBLIC.

insolation. Only 4% of all roofs suffered complete blocking of the Sun's direct rays and so may be considered as unfit for any form of solar collection. The remaining 13.5% of all roofs lost, by shading, more than 50% of the solar radiation that would otherwise fall on these near-horizontal surfaces.

Based on the wall and roof exposures to the Sun, it was found that 30% of all city houses suffered no loss, due to obstructions, of the theoretically-available direct solar insolation falling on the house walls and roof. Approximately 63.5% of all city houses represented in the sample lost between 10 and 20% of the direct solar radiation falling on their walls and horizontal roofs. The remaining 6.5% of all urban houses may be considered as unfit for any type of solar-energy applications. The loss, due to blocking, among the last 6.5% of all urban houses amounted to more than 50%. It is clear that the least obstructive possibility, for the well-oriented houses is some form of roof-mounted collector for solar energy. On that basis, up to 80% of all urban houses, particularly multi-storey houses, were suitable for harnessing solar-energy.

From the responses of city dwellers to the question about low-temperature solar-energy applications for city and village needs, the consensus was that water heating, followed by house electrification (using solar cells) are perceived as the most desired applications in cities. However, irrigation and crop-drying were the most desired applications in the countryside A summary of the city dwellers subjective views towards the ranking of these applications according to rural and urban uses is shown in Fig. 5.

## ENERGY BALANCE

Analysis of this energy survey indicated that 20% of all city houses used electricity for lighting, cooking, water heating, space cooling and heating and for stimulating various other items of household equipment. Natural gas is used mainly for cooking. This applied to 15% of all the city houses investigated via the survey. On the other hand, 55% of all city houses represented in the survey employed wood, agricultural

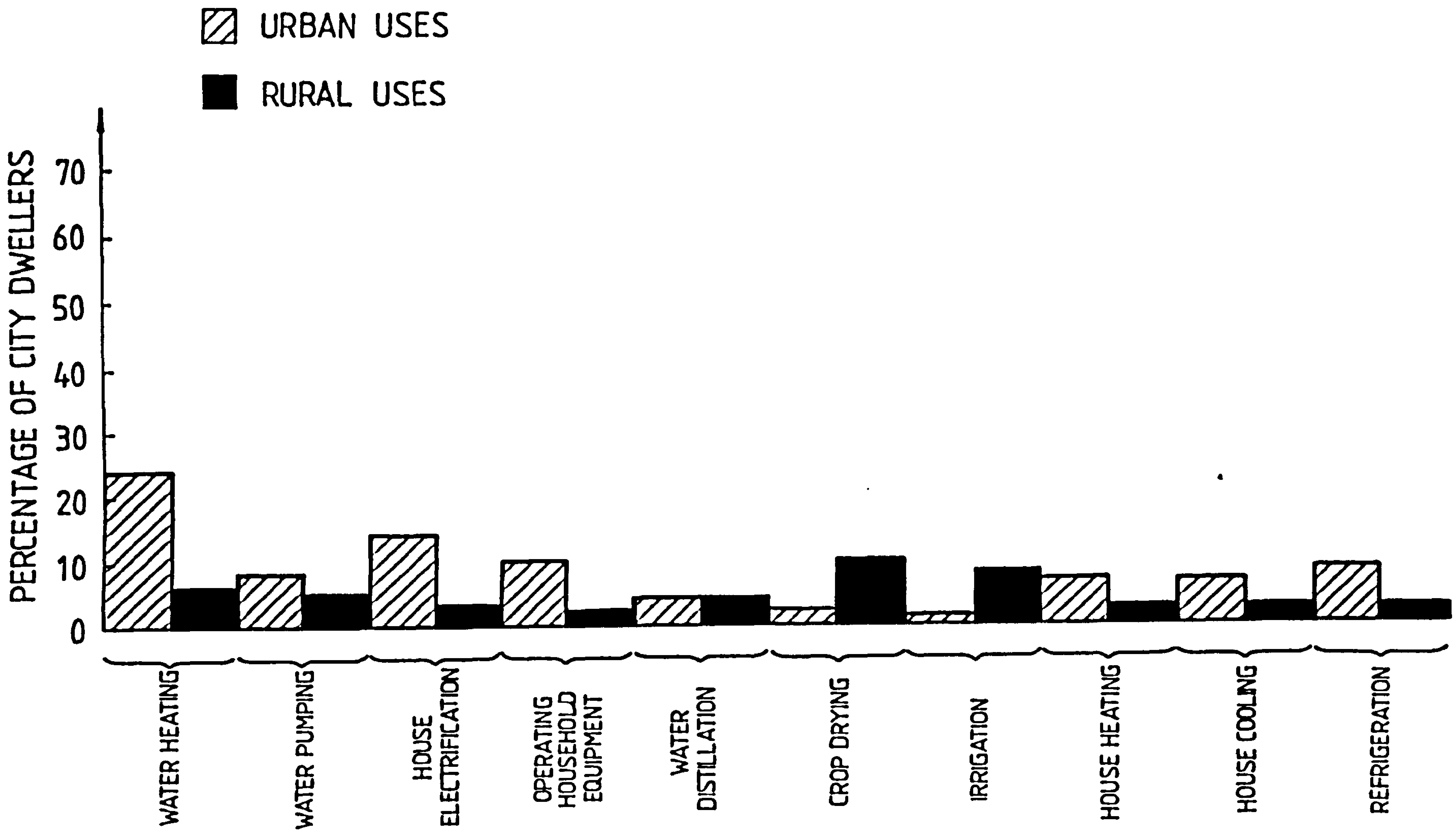



FIG. 5 CITY DWELLERS SUBJECTIVE VEIWS CONCERNING APPLYING SOLAR-ENERGY FOR USE IN THE URBAN AND RURAL RESIDENTIAL HOUSES IN THE YAR.

residues, or animal wastes for cooking and water heating. This percentage is lower than that obtained by the Central Planning Organisation's 1977 fertility survey {5}. Only 3% of all city houses represented in the present survey employed kerosene for either lighting, cooking or water heating. The remaining 7% of all city houses considered used charcoal for cooking, heating food, as well as for water and space heating.

Energy consumptions in the city houses of the Yemen have been classified as follows:-

APPLIANCE LOADS

This arises due to the use of radios, TV sets, washing machines, refrigerators and water pumps: it is satisfied predominantly by electricity. The total magnitude of the load was calculated via

$$\dot{Q}_{ap} = \sum_{i=1}^{n} P_i \eta_i \Delta t_i \qquad \ldots (1)$$

where $\eta_i$ is the efficiency of the ith appliance obtained from the manufacturer's catelogue. Table 2(i) summarises, according to the type of house and its geographical location, the values of $\dot{Q}_{ap}$ as calculated via Eq.(1).

LIGHTING LOAD

The major proportion ($\sim$ 96%) of this load is provided by electricity; the remaining 4% by kerosene. It was defined as the energy required to give adequate illuminations in the various rooms, halls etc., of the house. Its magnitude was calculated using

$$\dot{Q}_L = \bar{P}_T \Delta t \qquad \ldots (2)$$

It was necessary to estimate the actual average total power, $\bar{P}_T$, used to illuminate the various rooms in the house as well as the actual operating period, $\Delta t$. The estimation of $\Delta t$ involved the multiplication of the

# TABLE 2

## PARAMETERS USED IN CALCULATING THE ENERGY LOADS FOR THE TYPICAL CITY HOUSE IN THE YEMEN

### TABLE 2(i) LOAD $\dot{Q}_{ap}$ DUE TO DOMESTIC APPLIANCES PER TYPICAL HOUSE

| Region's Capital | Energy-demand Load $\dot{Q}_{ap}$ (Wh/day) | | | | |
|---|---|---|---|---|---|
| | Stone Houses | Red-brick Houses | Mud Houses | Type (i) Vernacular Houses | Type (ii) Vernacular Houses |
| Sana'a | 1407 | 841 | 841 | 1407 | 1473 |
| Taiz | 1303 | - | - | 1303 | 1358 |
| Al-Hodiedah | 1616 | 992 | - | 1616 | 1726 |
| Ibb | 990 | - | - | 990 | 1020 |
| Dhamar | 990 | 578 | 578 | 990 | 1020 |
| Hajjah | 766 | - | - | 766 | 786 |
| Al-Mahweet | 479 | 259 | 259 | 479 | 483 |
| Al-Beida | 719 | 399 | 399 | 719 | 719 |
| Ma'arib | - | - | 105 | - | - |

(- no information available from the present survey) maximum period during which the artificial illumination might be 'switched on" (which is explained later) by a "light use factor", i.e. the fraction of the day during which artificial illumination is employed somewhere in the house, i.e.

$$\Delta t = f_\ell \, \Delta t_s \qquad \ldots (3)$$

where $\Delta t_s$ is the total number of hours of darkness minus the average period of sleep: this represents the maximum theoretical operating time per day, and $f_\ell$ is the light-use factor. The maximum theoretical operating time, $\Delta t_s$, was determined by subtracting the sum of the annual daily average number of sunshine hours (i.e. 9 hours per day - see reference {8}) and the standard number of sleeping hours (i.e. 8 hours per day) from the 24-hour considered period. Accordingly, $\Delta t_s$ equals 7 hours per day. It is reasonable to assume that the factor $f_\ell$ was unity and 0.1 for the most and the least frequently occupied rooms in the house respectively, and so a representative value for the light-use factor in the house would be 0.55. To allow for the occupant's behaviour with respect to switching the lights on-and-off in the various rooms of the house, and for the seasonal variations with respect to daylight duration, the average value of $f_\ell$ was reduced by 0.05 to yield, using equation (3), an actual operating time, $\Delta t$, of 3.5 hours per day. The next step involved the estimation of the actual average total power used to illuminate the rooms of the house. In each geographical location, the number of rooms were determined from an analysis of the survey data. The rooms were then classified according to floor area, A, into four categories (i.e. j=1, 2, 3 or 4), namely

$$1 \ m^2 \leqslant A < 5 \ m^2$$

$$5 \ m^2 \leqslant A < 10 \ m^2$$

$$10 \ m^2 \leqslant A < 20 \ m^2$$

$$20 \ m^2 \leqslant A < 50 \ m^2$$

The first category includes toilets, kitchens, small halls, stairways, as well as sleeping, sitting, reading and dining rooms. The second category contains medium-size sleeping, sitting and reading rooms. Large sitting and receiving rooms, as well as large halls, were grouped in the third category. Social gathering rooms and spacious receiving rooms were deemed to be in the fourth category. The aim of such a classification was to establish the number of lamps required to provide various rooms with sufficient illumination. According to local practices, rooms in the first, second, third and fourth categories are illuminated respectively by one, two, three or four lamps. These were either 40W fluorescent lamps, 60W tungsten lamps, or an appropriate combination of both types. Because of these options, it was assumed that the rooms could be illuminated in three different ways. In the first, we assumed that rooms in all the categories were illuminated by 40W fluorescent lamps. Accordingly, the total power, $P_{Tf}$, used to illuminate the various rooms is given by:

$$P_{Tf} = \sum_{j=1}^{4} n_j \, n_{j\ell} \, P_f \qquad \dots (4)$$

In the second lighting mode, it was assumed that various rooms in all four categories were illuminated by 60W tungsten lamps. Consequently, the total power, $P_{Tt}$, used to illuminate the various rooms, is given by:

$$P_{Tt} = \sum_{j=1}^{4} n_j \, n_{j\ell} \, P_t \qquad \dots (5)$$

Rooms with floor areas exceeding 10 square meters were usually illuminated by fluorescent as well as tungsten lamps. For example, rooms in the third category were illuminated either by two 40W fluorescent lamps and one 60W tungsten lamp, or vice versa. However, rooms in the fourth category were illuminated using three different arrangements: either by three 40W fluorescent lamps and one 60W tungsten lamp, or vice versa, or two 40W fluorescent and two 60W tungsten lamps. The average power in any of these arrangements used to illuminate various rooms is given by:

$$\bar{P}_{Tft} = \left[\sum_{j=1}^{2} n_{j\ell}\left(\left(P_f + P_t\right)/2\right) + \sum_{j=3}^{4} \left(n_j/(j-1)\right)\left(n_{fjm} P_f + n_{tjm} P_t\right)\right] \qquad \dots (6)$$

where $n_{fjm}$, $n_{tjm}$ are respectively the number of fluorescent and tungsten lamps used to illuminate the various rooms in the house, and $m(=j-1)$ is an integer accounting for the different ways in which the room may be illuminated. The first term of equation (6) gives the average total power used to illuminate the rooms in the first and second room area categories. For these, the rooms were usually illuminated using either 40W fluorescent lamps or 60W tungsten lamps and therefore the total power i.e.

$$\sum_{j=1}^{2} n_j(n_{j\ell}(P_f + P_t))$$

was taken as the mean of the two alternatives. The second summation term on the right-hand side of equation (6) gives the average total power used to illuminate the rooms in the third and fourth room area categories. These rooms could be illuminated in (j-1) ways and therefore we divided the total power, i.e.

$$(n_j(n_{fjm}\, P_f + n_{tjm}\, P_t)),$$

by the number of possibilities in which the room in the third and fourth categories could be illuminated. Thus the actual power provided by electricity and used to illuminate the various rooms in the house lies somewhere between those predicted by equations (4), (5) and (6). In this analysis, it was taken as the average of the three predictions. To account for that portion of the lighting load provided by kerosene, we added to the above average, the appropriate power. Thus the actual total power, $\bar{P}_T$, used to illuminate the rooms in the house is given by:

$$\bar{P}_T = \left[\{(P_{Tf} + P_{Tt} + \bar{P}_{Tft})/3\; n_h\} + P_k\right] \qquad \ldots (7)$$

where $n_h$ is the total number of houses in the given geographical location, and $P_k$ was the power provided by kerosene when used for illumination: $P_k$ was estimated, for each house, by determining from the reported monthly bills paid for kerosene, the corresponding energies (in Whr) and dividing the result by the actual operating time. Once the actual average total power used to illuminate the various rooms in the house was estimated, the weighting procedure shown in Figure 4 of this analysis was employed to obtain $\bar{P}_T$ for the various types of houses considered in this survey - see Table 2(ii).

TABLE 2(ii) LIGHTING LOAD PER TYPICAL HOUSE

| Region's Capital | Actual Calculated Average Total Power Used To illuminate the rooms in the house $\bar{P}_T$, (W) | | | | |
|---|---|---|---|---|---|
| | Stone Houses | Red-brick Houses | Mud Houses | Type (i) Vernacular Houses | Type (ii) Vernacular Houses |
| Sana'a | 104 | 107 | 132 | 104 | 102 |
| Taiz | 98 | - | - | 105 | 101 |
| Al-Hodiedah | 82 | 94 | - | 93 | 68 |
| Ibb | 100 | - | - | 96 | 84 |
| Dhamar | 112 | 127 | 138 | 101 | 99 |
| Hajjah | 114 | - | - | 106 | 102 |
| Al-Mahweet | 135 | 151 | 167 | 130 | 125 |
| Al-Beida | 92 | 106 | 116 | 88 | 84 |
| Ma'arib | - | - | 87 | - | - |

(- no information available from the present survey)

WATER-HEATING LOAD

This according to the house considered, was provided by electricity, wood, kerosene and/or charcoal. The water heating load, $\dot{Q}_{wh}$, was determined by using an expression from reference {9}, modified by the daily use function, that is, the fraction of the day during which hot water was used, i.e.

$$\dot{Q}_{wh} = K(T_h - \bar{T}_a) \qquad \dots (8)$$

where $T_h$ is the hot-water temperature. In this analysis, $T_h$ is taken to be equal to 60°C {9}. In calculating the numerical values for the parameter K we assumed, in accordance with reference {9}, that on average a person would use 100 litres of hot water per day: see Table 2(iii).

COOKING LOAD

Natural gas, wood, charcoal and electricity are used for cooking in the city houses. By estimating, from the monthly bills paid for natural gas (as obtained from an analysis of question 11 in the survey), the rate of energy consumed (in kWhr/day), and then dividing the result by the estimated proportion, $F_n$, of the cooking load provided by natural gas, the rate of energy used for cooking can be deduced from:

$$\dot{Q}_{co} = 30.3\ \eta_o(P_n / F_n) \qquad \dots (9)$$

where 30.3 is the conversion factor from Rial/month to kWhr/day, and $\eta_o$ is the efficiency of the gas oven which, in the YAR, is ordinarily between 0.5 and 0.6 {9} - see Table 2(iv).

SPACE HEATING AND SPACE COOLING LOADS

These loads were satisfied by more than one energy resource, viz

$$\dot{Q}_T = \dot{Q}_{ap} + \dot{Q}_L + \dot{Q}_{wh} + \dot{Q}_{co} + \dot{Q}_{hh} + \dot{Q}_{hc} \qquad \dots (10)$$

Table 2 (iii) WATER-HEATING LOAD PER TYPICAL HOUSE

| Region's Capital | Stone houses | | Red-brick houses | | Mud houses | | Type (i) vernacular houses | | Type (ii) vernacular houses | |
|---|---|---|---|---|---|---|---|---|---|---|
| | K (Wh $^oC^{-1}day^{-1}$) | $N_p$ | K (Wh $^oC^{-1}day^{-1}$) | $N_p$ | K (Wh $^oC^{-1}day^{-1}$) | $N_p$ | K (Wh $^oC^{-1}day^{-1}$) | $N_p$ | K (Wh $^oC^{-1}day^{-1}$) | $N_p$ |
| Sana'a | 70 | 5 | 70 | 5 | 86 | 5 | 70 | 5 | 70 | 5 |
| Taiz | 123 | 4.4 | - | - | - | - | 132 | 4.7 | 126 | 4.5 |
| Al-Hodiedah | 218 | 7.8 | 250 | 8.9 | - | - | 218 | 7.8 | 180 | 6.4 |
| Ibb | 71 | 5.1 | - | - | - | - | 70 | 5 | 61 | 4.4 |
| Dahmar | 61 | 4.4 | 70 | 5.0 | 74 | 5.3 | 55 | 3.9 | 54 | 3.9 |
| Hajjah | 77 | 5.5 | - | - | - | - | 71 | 5.1 | 70 | 5.0 |
| Al-Mahweet | 71 | 5.1 | 79 | 5.7 | 88 | 6.4 | 70 | 5 | 65 | 4.6 |
| Al-Beida | 66 | 4.7 | 76 | 5.5 | 83 | 5.9 | 63 | 4.5 | 61 | 4.4 |
| Ma'arib | - | - | - | - | 71 | 5.1 | - | - | - | - |

( - no information available from the present survey)

Table 2 (iv) COOKING LOAD PER TYPICAL HOUSE

| Region's Capital | Total expenditure, in Rial*/month, and proporations of the cooking load provided by natural gas | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Stone Houses | | Red-brick Houses | | Mud Houses | | Type (i) Vernacular Houses | | Type (ii) Vernacular Houses | |
| | $P_n$ | $F_n$ | $P_n$ | $F_n$ | $P_n$ | $F_n$ | $P_n$ | $F_n$ | $P_n$ | $F_n$ |
| Sana'a | 94 | 0.5 | 71 | 0.4 | 71 | 0.4 | 94 | 0.5 | 118 | 0.6 |
| Taiz | 141 | 0.6 | - | - | - | - | 141 | 0.6 | 165 | 0.8 |
| Al-Hodiedah | 188 | 0.85 | 94 | 0.5 | - | - | 188 | 0.8 | 202 | 0.9 |
| Ibb | 71 | 0.4 | - | - | - | - | 71 | 0.4 | 94 | 0.45 |
| Dhamar | 71 | 0.4 | 71 | 0.4 | - | - | 71 | 0.4 | 71 | 0.4 |
| Hajjah | 47 | 0.2 | - | - | - | - | 47 | 0.2 | 71 | 0.3 |
| Al-Mahweet | 47 | 0.15 | 47 | 0.15 | 47 | 0.15 | 47 | 0.15 | 47 | 0.2 |
| Al-Beida | 47 | 0.20 | 47 | 0.2 | 47 | 0.2 | 47 | 0.2 | 47 | 0.3 |
| Ma'arib | - | - | - | - | 23 | 0.1 | - | - | - | - |

(* Conversion factor 1Rial=0.1£ or 0.169 U.S.$ as at June 1985)

( - no information available from the present survey)

For a given type of house in a given geographical location, the space heating load, $\dot{Q}_{hh}$, was calculated in accordance with:

$$\dot{Q}_{hh} = (UA)_h \, dd_h \qquad \ldots (11)$$

where $dd_h$ was the number of heating degree-days in a month, and $(UA)_h$ was the product the building's overall heat loss coefficient and the total external house area {9}. In this analysis, the number of heating degree-days in a month was calculated using 18.3°C as the reference temperature, rather than 22°C, because the sundry energies released from within the building (as a result of the operation of the oven, lights, appliances, the presence of people and solar gains through the windows) were sufficient to raise the average diurnal indoor temperature from 18.3°C to the comfort level of 22°C. So

$$dd_h = (18.3 - \bar{T}_a)N \qquad \ldots (12)$$

where N was the number of days for the selected calendar month, and $\bar{T}_a$ was the annual daily average ambient air temperature - see Table 2(v). The building's overall heat loss coefficient time the houses overall total external surface area (including that of the floor) product, $(UA)_h$ was determined from the details of the building construction, i.e.,

$$(UA)_h = (UA)_w + (UA)_r + (UA)_g + (1200/3600)\,\dot{V} \qquad \ldots (13)$$

where $(UA)_w$, $(UA)_r$ and $(UA)_g$ are respectively the heat loss coefficient area products for walls, roof and floor and glazed elements. The last term on the right-hand side of equation (13) represents the rate of heat loss due to ventilation {10}, where $\dot{V}$ is the volume of air (at atmospheric pressure) lost from the house in cubic metres per hour. Solving equation (10) for $\dot{Q}_{hc}$, taking into consideration equations (1) through to (13), we obtain:

$$\dot{Q}_{hc} = \left[\dot{Q}_T - 30.3\,\eta_o(P_n/F_n) - K(T_h - \bar{T}_a) - \bar{P}_T\,\Delta t - \sum_{i=1}^{n} P_i\,\eta_i\,\Delta t_i - \dot{Q}_{hh}\right] \qquad \ldots (14)$$

Table 2 (v) MEAN AMBIENT TEMPERATURE AND PER CAPITA INCOME FOR A TYPICAL HOUSE

| Region's Capital | Annual daily average ambient air temperature, $\bar{T}_a$ ($^oC$) | Annual per capita income of "head of house", as obtained from the survey data I (U.S. $/YEAR) | | | | |
|---|---|---|---|---|---|---|
| | | Stone houses | Red-brick houses | Mud houses | Type (i) vernacular houses | Type (ii) vernacular houses |
| Sana'a | 15.1 | 564 | 561 | 531 | 567 | 567 |
| Taiz | 16.4 | 592 | - | - | 596 | 568 |
| Al-Hodiedah | 22.5 | 368 | 420 | - | 422 | 410 |
| Ibb | 15.1 | 472 | - | - | 462 | 415 |
| Dhamar | 15.1 | 499 | 471 | 459 | 454 | 454 |
| Hajjah | 15.1 | 425 | - | - | 392 | 384 |
| Al-Mahweet | 15.1 | 378 | 376 | 364 | 400 | 400 |
| Al-Beida | 16.4 | 520 | 430 | 420 | 511 | 450 |
| Ma'arib | 18.1 | - | - | 350 | - | - |

( - no information available from the present survey)

The distributions of the energy load per house, $\dot{Q}_T$, by cities and daily functional application of energy, are shown in Fig. 6. The cooking load, except for red-brick and type (i) vernacular houses, i.e. houses with first storeys built in stone and the upper storeys of a less dense material - see reference {4}, located in Al-Hodiedah city, was the prime consumer of energy. For example, in Hajjah, Al-Beida, Al-Mahweet and Ma'arib cities, the cooking load represented more than 45% of the total domestic energy load. For other capitals, the cooking demand amounted to a little over 30% of the domestic energy load. This variation is attributed to differences of educational, economic and social factors. Although it is traditional for those living in Sana'a, Taiz, Al-Hodiedah, Ibb or Dhamar to use wood for bread making on alternate days, this is not so for the other cities. This local sociological difference reflects the greater awareness concerning energy thrift by the populations of the more developed cities. It is also clear from Table 2(iv) that the contribution of natural gas, in those cities where the cooking load represented more than half the total load, was relatively small ($\sim$ 20%). This implies that wood, which is more expensive than natural gas, satisfies the largest proportion of the cooking energy demand in these cities. Add to this the absence of energy-thrift measures of any kind, then the wide variations of the cooking load, as we go from the cities of zone II to those of zone I, may be appreciated.

Depending on the type of house and its geographical location, water-heating, space-cooling or space heating loads were the second priority with respect to energy consumptions - see Fig. 6. For example, in all houses located in the city of Ma'arib in the east, Al-Mahweet and Hajjah in the west, and Ibb in the interior Ibb plain, the water-heating load was the second largest consumer for energy followed respectively by the space-cooling and the space-heating loads. Appliances, and lighting loads ranked according to their respective consumptions, each contributed the least percentage of the energy load. For example, lighting and appliances loads represented respectively, at most 3% and 10% of the total energy domestic load. On the other hand, the space-heating load represented a negligible percentage of the house energy load in Al-Beida, Ma'arib, and Al-Hodiedah cities. It was negligible in Al-Hodiedah city for all types of houses. Thus the regional distribution of the domestic energy load

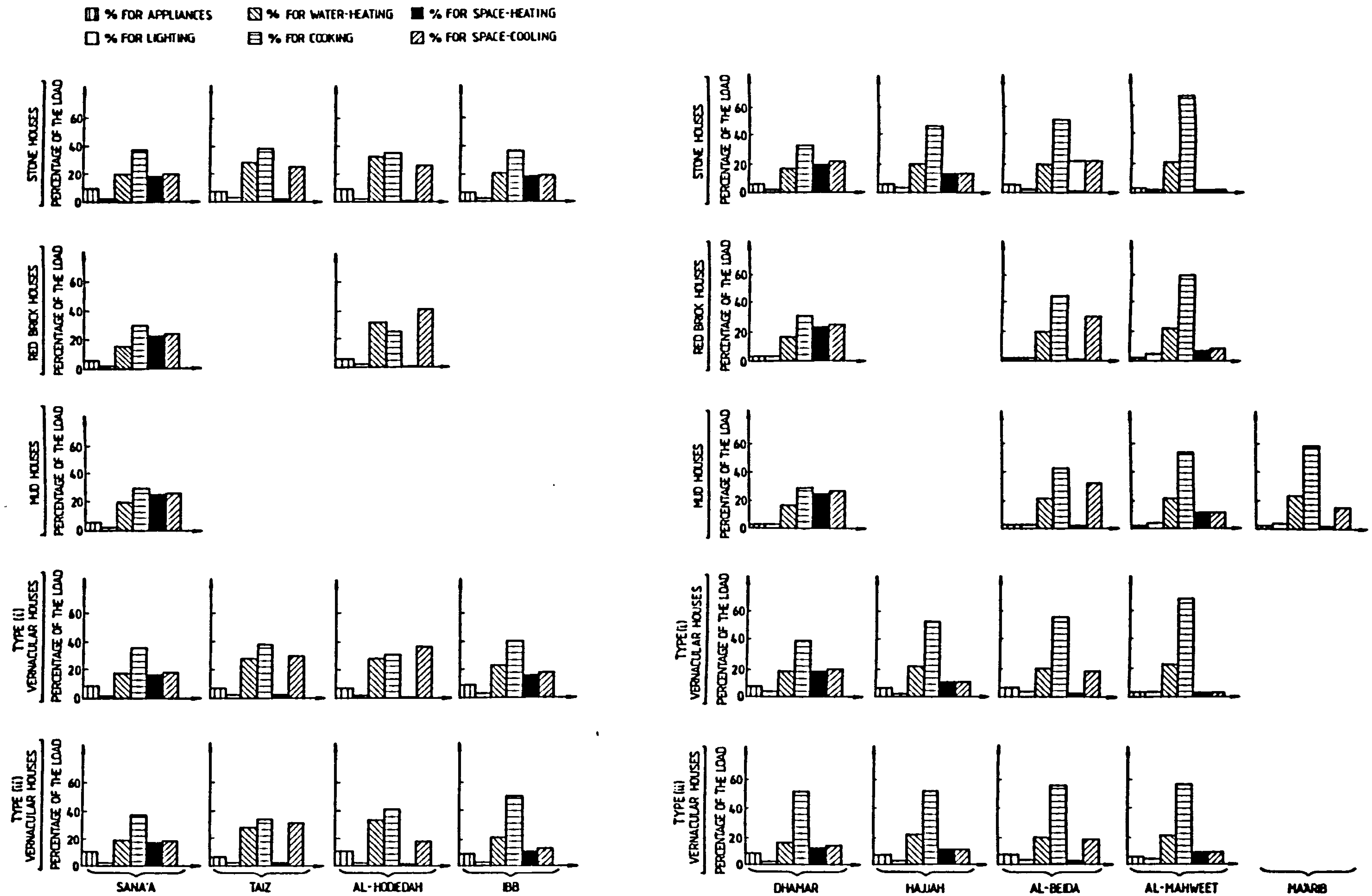



FIG. 6. FUNCTIONAL USES OF ENERGY IN A TYPICAL CITY RESIDENTIAL HOUSE IN THE YEMEN ARAB REPUBLIC AS PERCENTAGES OF THE TOTAL HOUSE ENERGY LOAD.

showed that the cooking load, except for some types of houses in Al-Hodiedah city, was the principal consumer of energy in the city houses of the Yemen. The variations from one type of house to another were attributed to the differing architectural designs, $(UA)_h$ values and locations of the houses. More specifically, the more important factors which cause the variations of the domestic energy load from one type of house to another were:

- Number of occupants and their daily usage of hot water - see Table 2(iii)
- Visits to the city family by relatives from rural and urban areas: this led to significant increases in cooking loads
- The $(UA)_h$ product, which indicates the thermal design effectiveness of the house and influences the magnitudes of the space-heating or space-cooling loads
- Type and efficiency of the electric equipment used in the house. These had direct influences, see equation 1, on the appliance's load
- Shading obstructions affecting how much solar energy falls on the house walls and 'horizontal' roof.

## CONSUMPTION PER HEAD OF POPULATION

The per capita energy consumption, $Q_c$, for a given type of house in a given geographical location is defined by:

$$Q_c = \dot{Q}_T/N_p \qquad \ldots (15)$$

where $\dot{Q}_T$ is the total energy load, plotted for all types of house in Fig.7; and $N_p$ is the number of occupants in the house-see Table 2 (iii).

If one kWh costs 1.1 Rial, i.e. 0.169 U.S.$ at June 1985 exchange rates, then the per capita expenditure on fuel, C, is given by:

$$C = 0.169\ P_c \qquad \ldots (16)$$

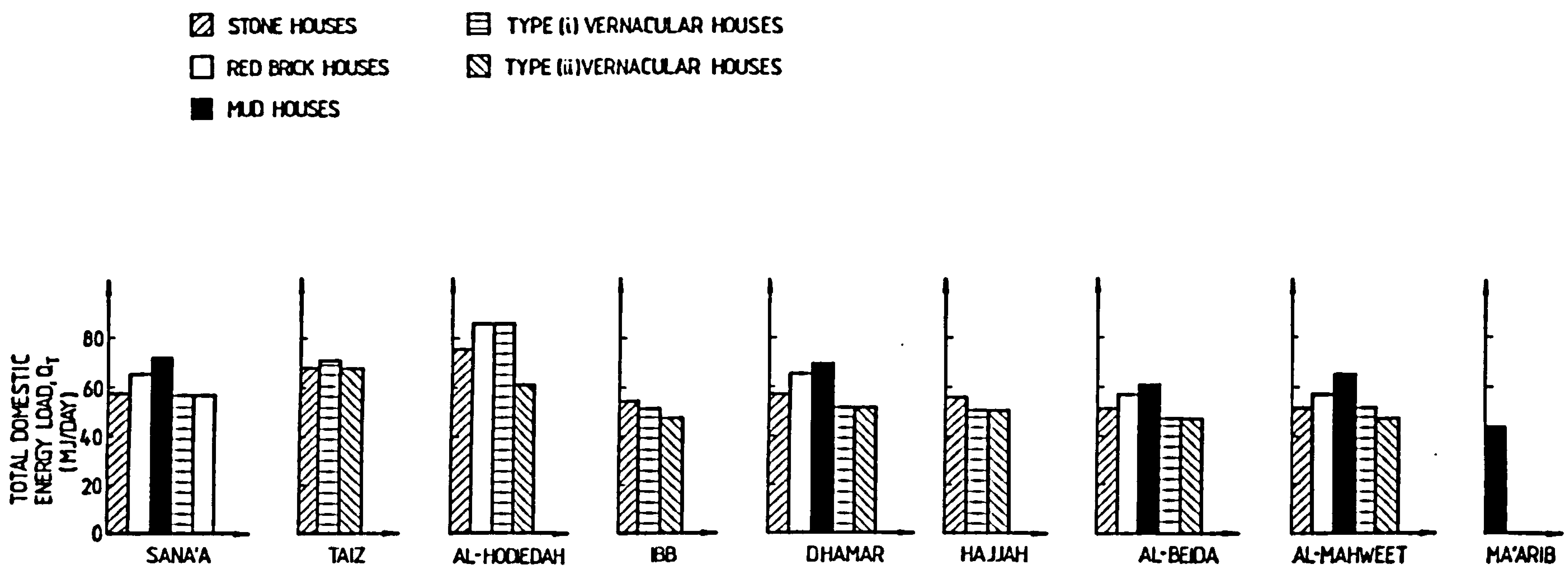



FIG 7. TOTAL ENERGY LOAD PER AVERAGE HOUSE ACCORDING TO TYPE OF HOUSE AND GEOGRAPHIC LOCATION.

The percentage $\phi$ of income spent on fuel is defined as the ratio of the annual per capita expenditure so incurred to the annual per capita income, i.e.,

$$\phi = (365C/I)x100 \qquad \ldots (17)$$

where $I$ = per capita income, as listed in Table 2 (v)

The regional distributions of $Q_c$ and C are shown respectively in Figs. 8a and b. Accordingly, and depending on the type of house, the per capita consumption varied from 2.3 kWh/day (i.e. 8.3 MJ/day) to 4.32 kWh/day (i.e. 15.6 MJ/day). The per capita cost ranged from 0.4$/day to 0.75$/day. Thus a family of five would spend between 2 and 3.5 $/day on fuel. Taking the per capita income for the whole country as 500$/year, i.e. 2500$/year for this family {2}, then 29 to 51% of the income would be spent on fuel. The regional variation of $\phi$ is plotted, for all types of houses considered by this energy survey, in Fig. 8c.

The variation of the energy consumption and consequently the percentage of the income spent on fuel is explained by Fig. 9: the house energy load, $\dot{Q}_T$, was split between the imported energy resources, consumed in the forms of electricity and natural gas, and the local energy resources, i.e. wood, animal waste, charcoal, and agricultural residues. More than half of the house energy load is provided by local energy resources in the cities of zone I and in Taiz of zone II. The situation was different in the cities of Al-Hodiedah and Sana'a where, for some types of house, more than half the house energy load was provided by imported energy resources, i.e. electricity and natural gas. It is worthy of note that the cost per kWh provided by the local resources, at least for the time being, is higher than that of electricity or natural gas. This strange phenomenon indicates why the percentage of income spent on fuel in the cities of zone I was higher than that, except for Taiz, of the cities of zone II. It is also interesting to note that red-brick and mud houses use local energy resources more frequently than any other types of houses. In these houses more than half the total energy load, regardless of geographical looation, was provided by wood, charcoal, animal waste, and/or agricultural residues. On the other hand, type (ii) followed by type (i) vernacular houses, particularly in Al-Hodiedah city, relied on electricity and natural gas more than any other type of house represented in this energy survey.

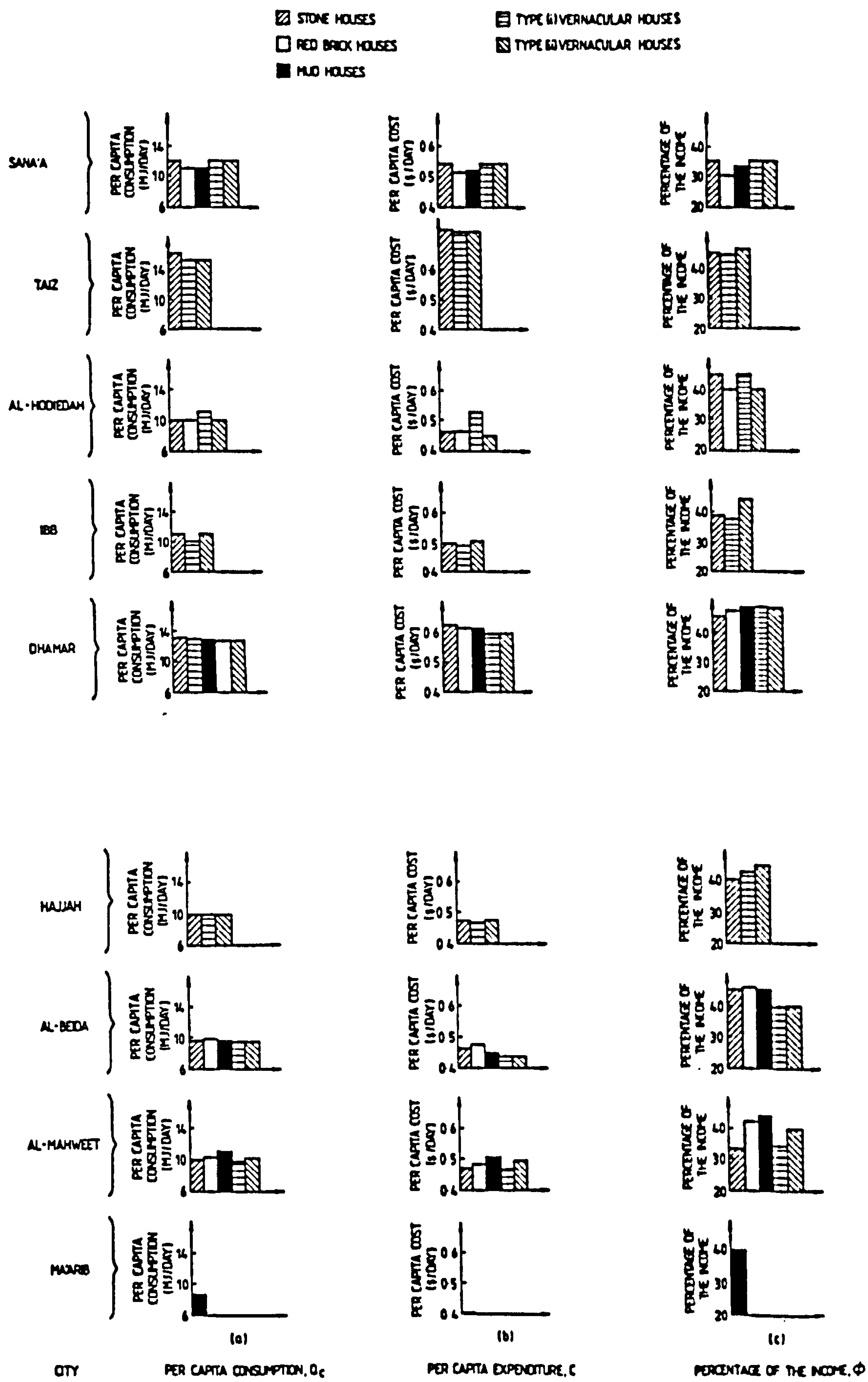



FIG. 8. DISTRIBUTION OF THE PER CAPITA CONSUMPTION, PER CAPITA EXPENDITURE, AND PERCENTAGE OF INCOME ACCORDING TO THE TYPE OF HOUSE AND GEOGRAPHIC LOCATION.

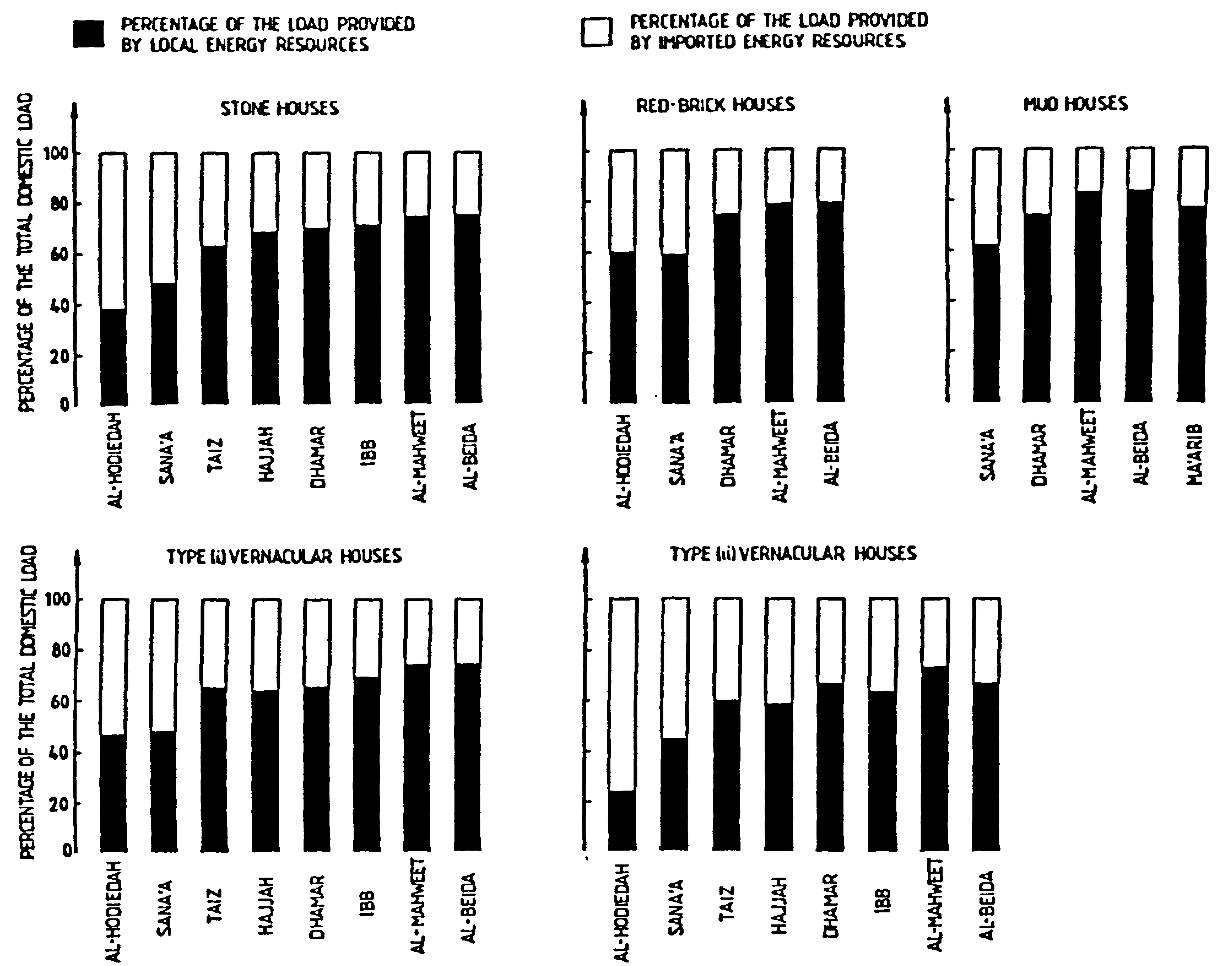



FIG. 9. DOMESTIC ENERGY LOAD AS SATISFIED BY INDIGENOUS AND IMPORTED ENERGY RESOURCES

Nevertheless, local energy resources still dominate the provision of domestic energy in the whole country. This is in spite of the fact that the recent indigenous oil discovery has not, as yet, had a national impact on the energy-consumption patterns.

## CONCLUSIONS AND RECOMMENDATIONS

The presented tables and figures suggest that there are good prospects for passive solar-energy systems in existing urban houses in the Yemen. But there is a need to :-

- Develop an awareness and interest amongst architects and builders concerning harnessing and applying solar energy.
- Foster the acceptability of, and desire for, integrating solar energy components within building structures.
- Improve the public's respect for using solar energy, not only as a source of illumination, but also as a source of power.
- Introduce energy-thrift measures, such as government regulations limiting the $(UA)_n$ values for buildings according to international recommendations {10}.

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# C H A P T E R T W O

## SOLAR INSOLATION UPON THE YEMEN ARAB REPUBLIC

# GLOSSARY

**Actinograph** — A device in which a mechanical linkage is used to record temperature differences between a black-coated bimetallic strip exposed to solar radiation and two similar bimetallic strips either painted white or shielded from solar radiation. Because the response time is slow, this instrument is only suitable for obtaining estimates of total global radiation for a large time interval.

**Pyranometer** — An instrument for the measurement of the solar radiation received from the whole hemisphere. It is suitable for the measurement of the global or sky radiation.

**Pyrheliometer** — An instrument for measuring the intensity of direct solar radiation at normal incidence.

**Sky radiation** — Downward diffuse solar radiation as received on a horizontal plane from a hemispherical surface bounded by the horizon with the exception of that part of the surface bounded by the solid angle subtended by the sun's disc.

# NOMENCLATURE

| | | |
|---|---|---|
| A | Arbitrary constant in eqn. (1) | |
| A(i), i=0 to 6 | Fourier coefficient in eqn. (12) | |
| A(ℓ), ℓ=0 to 6 | Fourier coefficient in eqn. (11) | |
| A(r), r=1 to 3 | Fourier coefficient in eqn. (7) | |
| A(s), s=0 to 4 | Fourier coefficient in eqn. (7) | |
| B | Arbitrary constant in eqn. (1) | |
| C(j), j=1 to 7 | Fourier coefficient defined by eqn.(15) | |
| c(i,j),(i=1 to 4, j=1 to 7) | Matrix used in eqn. (15) | |
| D | Daily diffuse solar insolation | MJ $m^{-2}$ |
| $D_c$ | Diffuse solar radiation flux from a clear sky defined by eqn. (13) | |
| $F_c$ | Cloud cover factor, see eqn. (17) | |
| G | Daily global insolation | MJ $m^{-2}$ |
| $\bar{G}$ | Average daily global insolation | MJ $m^{-2}$ |
| $G_c$ | Global solar radiation flux from a clear sky defined by eqn. (11) | |
| $H_o$ | Extra-terrestrial radiation on a horizontal surface defined by eqn. (2) | MJ $m^{-2}$ |
| $\bar{H}_o$ | Average daily extra-terrestrial radiation | MJ $m^{-2}$ |
| h | Mean relative humidity (per cent) | % |
| K | Zone parameter | |
| k | Parameter defined by eqn. (19) | |
| $I_c$ | Direct solar radiation flux from a clear sky defined by eqn. (12) | W $m^{-2}$ |
| $I_{sc}$ | Solar constant (= 1353 W $m^{-2}$) | |
| L | Number of month (i.e. January = 1, February = 2, etc.) | |
| m | Number of days in the month. | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $m^*$ | Effective air mass, see eqn. (17) | |
| $N$ | Theoretical length of insolation period | hr |
| $n$ | Actual diurnal duration of sunshine on specified area of Yemen | hr |
| $R$ | Rayleigh scattering coefficient (= 0.104) | |
| $S$ | $= n/N$ | |
| $T$ | Argument of the function defined by eqn. (8) | |
| $t$ | Rain parameter | |
| $W$ | Weighting factor | |
| $X$ | Parameter defined by eqn. (16) | |
| $x$ | Thickness of the ozone layer | m |
| $y$ | Day of the year | |
| $Z$ | Zenith distance defined by eqn. (10) | |
| $\alpha$ | Altitude defined by eqn. (9) | degrees |
| $\alpha_k$ | Noon altitude, see eqn. (6) | degrees |
| $\alpha_o$ | Ozone absorption coefficient (= 0.045), see eqn. (17) | |
| $\phi$ | Latitude | degrees |
| $\delta$ | Solar declination defined by eqn. (3) | degrees |
| $\omega$ | Hour angle, $=(12.5 - H) \times 15^{\circ}$; $H = 6$ to $19$ | degrees |
| $\omega_s$ | Sunset hour angle defined by eqn. (4) | degrees |
| $\tau$ | Opacity plus albedo effects, see eqn. (17) | |
| $\lambda$ | Latitude factor defined by eqn. (20) | |
| $\psi_{i,j}$ | Seasonal factor ($i=1$ for inland, $i=2$ for coastal, $j=1$ to $12$), see eqn. (19) | |

# CHAPTER 2

## SOLAR INSOLATION UPON THE YEMEN ARAB REPUBLIC

### AMBIENT ENERGY IN THE YEMEN

The average daily solar radiation in Sana'a, the capital city of the Yemen, is 22 MJ $m^{-2}$. This is equivalent to an annual energy supply of 8167 MJ $m^{-2}$. Some locations in the Yemen have longer hours of sunshine and may have even higher intensities of insolation. The amount of solar energy available throughout the country is so large that its potential as a future energy source deserves exploitation. Thus, harnessing solar energy in the Yemen appears to be a commercially viable proposition.

Energy currently represents more than 25 per cent of the total imports to the Yemen {1} and the demand for energy is increasing rapidly as industrialisation proceeds. It is therefore important that the Yemen, like many other countries, should harness indigenous sources of power, especially wind and solar energy.

### INSOLATION MEASUREMENTS

Sana'a University has installed three Eppley pyranometers and a sunshine duration recorder. In particular the following instruments were used:

(1) An Eppley precision spectral pyranometer, for the assessing of solar and sky radiation.

(2) An Eppley Angström pyrheliometer, for determining the magnitudes of direct solar radiation.

(3) An Eppley precision spectral pyranometer, with an iron shade, to measure the diffuse radiation.

(4) An actinograph for hourly observations of the global solar insolation.

In addition, pertinent measurements have been made by the Meteorological Department at Sana'a airport. The experimental data available to date, for the period January, 1977 to September, 1982, are summarised in Table 1.

The Yemen Arab Republic (see Fig. 1) can be divided geographically into three regions:

(i) The coastal zone bordering the Red Sea to the west.

(ii) A mountain range to the north.

(iii) The interior Ibb plain bounded on the east and on the north by a mountain range.

The long-term average climatic conditions for different locations within the interior plain are similar.

For this reason, the Sana'a data are thought to be representative of conditions generally prevailing in the Ibb plain. No solar data are available at present for the mountain area but, because of the distances involved and the difficulties in reaching parts of the mountain regions, it is reasonable, as a first approximation, to use the Sana'a data for predicting conditions there. However, for the mountain region, altitude must also be taken into consideration.

Due to the near-total previous absence of accurate solar radiation data bases for the Yemen {2} and the urgent need there to develop solar-energy systems for rural applications, three theoretical models will be reviewed and analysed.

Typical radiation curves which show the variations of solar intensity as functions of time are given in Fig. 2. Comparisons of the mean hourly values, maximum hourly values and minimum hourly values reveal:

(i) That the mean values per hour, in general, follow a smooth near symmetrical curve with a broad peak of 750 to 942 W $m^{-2}$ occurring at 12.00 (noon) to 13.00 h.

TABLE 1

EXPERIMENTAL OBSERVATIONS AND DEDUCTIONS THEREFROM FOR SANA'A, THE YEMEN

| Month | Average daily global insolation (MJ $m^{-2}$) | Average daily sunshine hours (hr) | Average daily ambient temperature (°C) | Mean of daily peak insolations during the month (W $m^{-2}$) | Maximum value of insolation during the month (W $m^{-2}$) | Average monthly global insolation (GJ $m^{-2}$) |
|---|---|---|---|---|---|---|
| Jan. | 19.4 | 9.1 | 18 | 803 | 886 | 0.601 |
| Feb. | 20.9 | 9.9 | 18 | 886 | 1 025 | 0.585 |
| Mar. | 23.4 | 9.0 | 19 | 750 | 1 025 | 0.725 |
| April | 24.8 | 9.1 | 23 | 914 | 1 163 | 0.744 |
| May | 24.8 | 8.9 | 23 | 803 | 997 | 0.769 |
| June | 24.1 | 8.8 | 25 | 914 | 1 025 | 0.723 |
| July | 23.8 | 7.1 | 23 | 720 | 914 | 0.738 |
| Aug. | 23.9 | 7.4 | 21 | 803 | 970 | 0.725 |
| Sept. | 23.8 | 8.7 | 18 | 914 | 970 | 0.714 |
| Oct. | 22.3 | 10.1 | 18 | 942 | 997 | 0.691 |
| Nov. | 19.4 | 9.7 | 18 | 886 | 914 | 0.581 |
| Dec. | 18.4 | 9.0 | 18 | 831 | 914 | 0.570 |

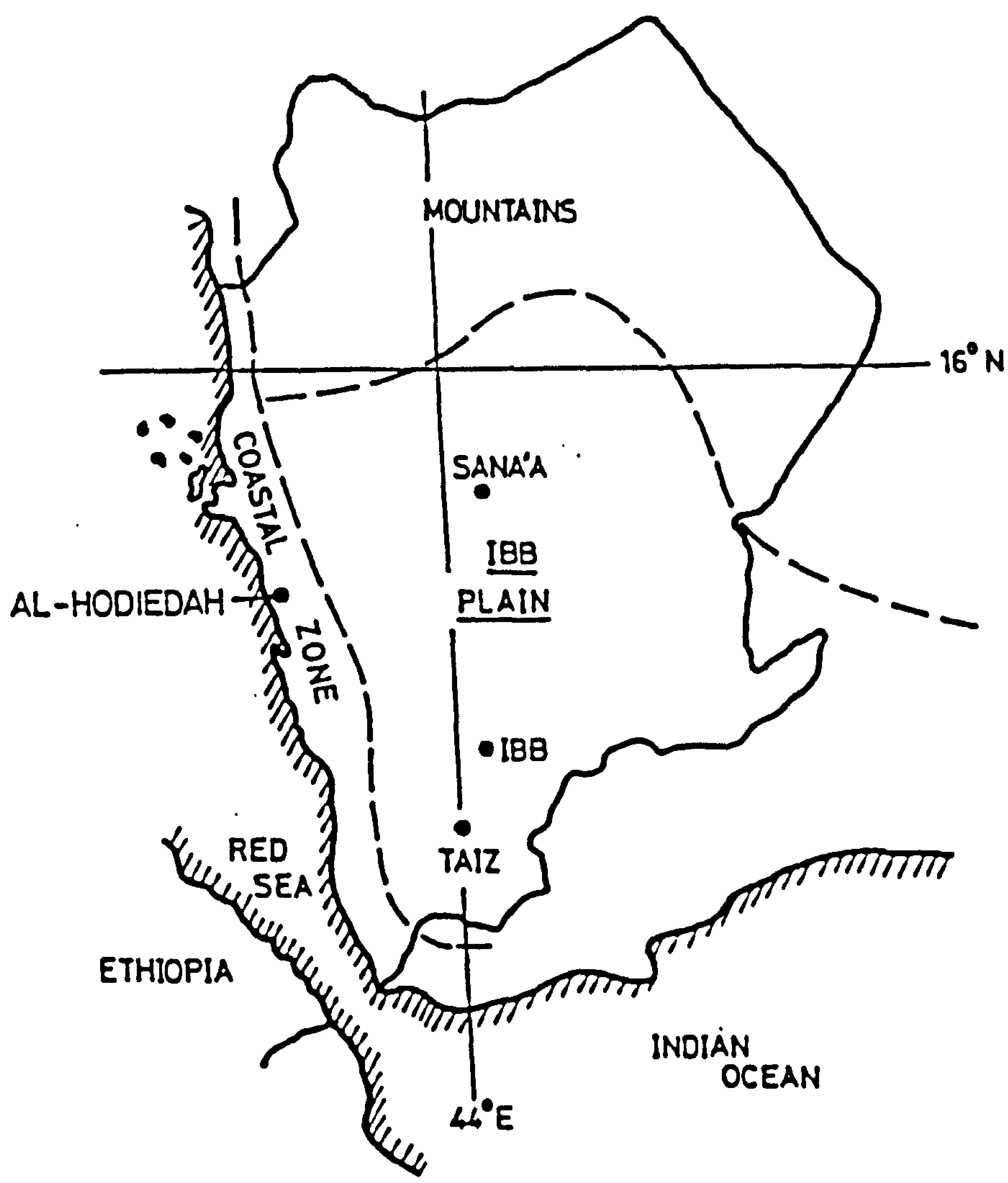


FIG. 1. LOCATION AND GEOGRAPHICAL REGIONS OF THE YEMEN ARAB REPUBLIC.

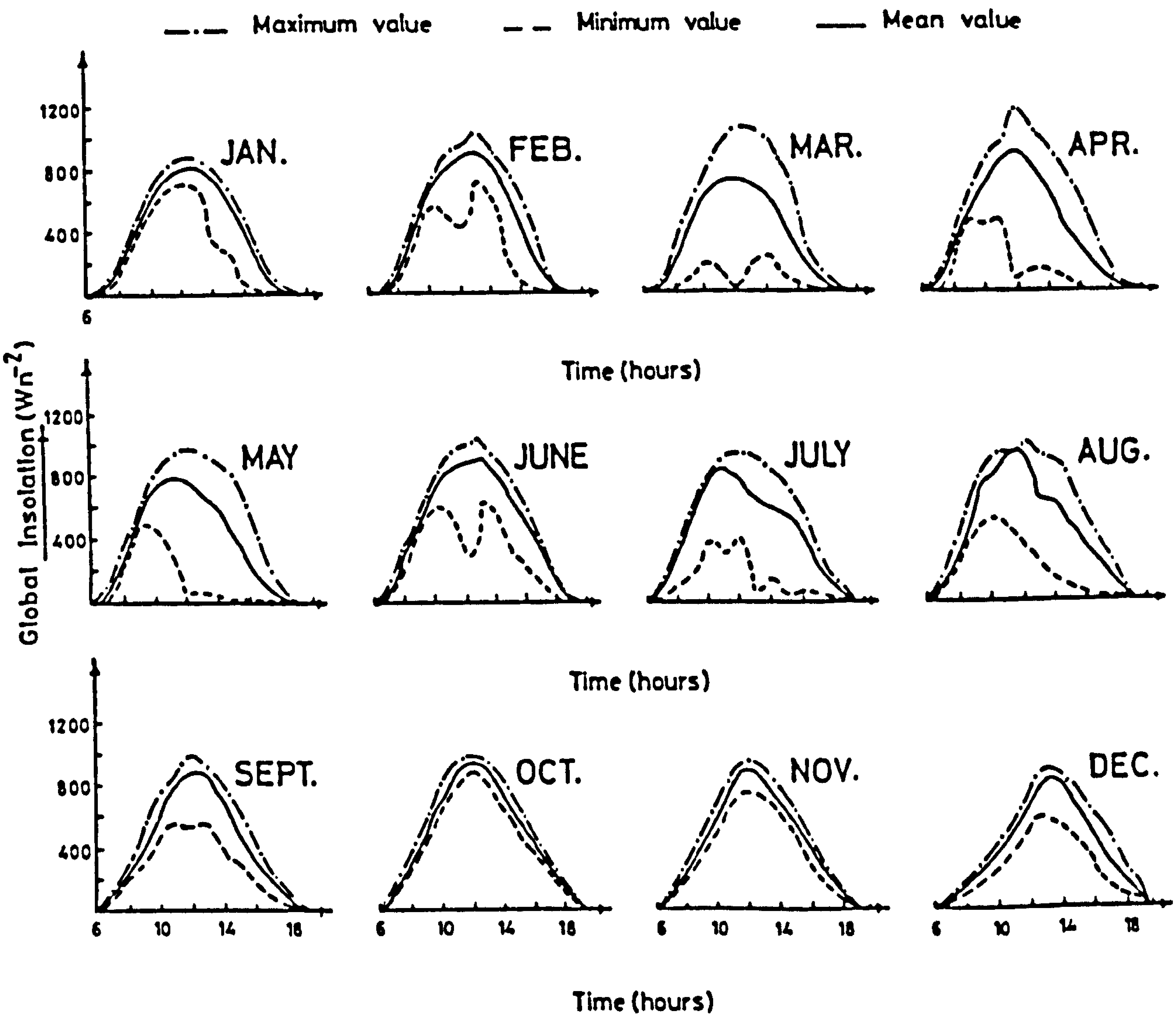


FIG. 2. MEAN MONTHLY DIURNAL VARIATIONS OF THE GLOBAL INSOLATION IN THE HORIZONTAL PLANE.

(ii) That the maximum values per hour follow a smooth curve with a sharp peak of 866 to 1163 W $m^{-2}$ at noon approximately.

(iii) That minimum values per hour vary from zero in the early morning to a maximum of 694 W $m^{-2}$ at noon approximately.

A summary of the daily values is given in Table 1.

## SOLAR RADIATION MODELLING

There have been many attempts to establish models which can predict the amount of global insolation available at any location {2-9}. These models have ranged in complexity from the complete radiative transfer function to some simple models which do not require large-store computers. The mathematical expressions for some of these empirical models are reviewed below.

Page {3} developed an earlier model by Angström {4} that used the sunshine duration as the model input to estimate the average daily solar radiation. It sought a linear relationship between global radiation levels and the number of sunshine hours. The average daily global insolation was predicted from:

$$\bar{G} = \bar{H}_o(A + Bn/N) \qquad \text{... (1)}$$

where:

$$H_o = (24I_{sc}/\pi)\left[1 + 0.033\cos(360y/365)\right]$$
$$\times\left[\cos\delta\cos\phi\sin\omega_s + (2\pi\omega_s/360)\sin\delta\sin\phi\right] \qquad \text{... (2)}$$

$$\delta = 23.45\sin(360(y + 284)/365) \qquad \text{... (3)}$$

and:

$$\cos\omega_s = -\tan\phi\tan\delta \qquad \text{... (4)}$$

The Liu and Jordan model {5} relates the ratio $D/H_o$ of daily rates of diffuse to extra-terrestrial irradiation, to the ratio $G/H_o$ of daily rates of global to extra-terrestrial irradiation. Although the method is applicable to daily, rather than hourly values, it has frequently been used to estimate hourly rates of diffuse radiation. The equation below, representing the Liu and Jordan correlation, will be used in this study:

$$D/H_o = 0.294(G/H_o) + 0.1445 \sin (4.97(G/H_o)) \qquad \ldots (5)$$

Barbaro et al {6} combined the monthly sunshine duration, the noon altitude of the sun on a particular day of the month and a zone parameter to estimate the average monthly global insolation on a horizontal surface. The following mathematical form of this model has been used in this investigation:

$$G = K\left((mn)^{1.24}(\alpha_k^{0.19})\right) + 10\,550(\sin \alpha_k^{2.1}) + 300(\sin \alpha_k)^3 \qquad \ldots (6)$$

Exell {7} developed a compact first-order random model for simulating daily totals of solar radiation and hourly radiation fluxes. Altitude, declination, zenith distance and latitude were the model inputs. From the day of the year, the Sun's declination was calculated by means of a Fourier series of the form:

$$\delta = \sum_{s=o}^{4} A(s) \cos(sT) + \sum_{r=1}^{3} A(r) \sin(rT) \qquad \ldots (7)$$

in which

$$T = (360(y - 80)/365) \qquad \ldots (8)$$

The sun's altitude, the zenith distance and the hourly radiation fluxes were calculated by means of eqns. (9) to (13).

Altitude,

$$\sin \alpha = \cos \omega \cos \delta \cos \phi + \sin \delta \sin \phi \qquad \ldots (9)$$

Zenith distance,

$$Z = (1 - \alpha/90) \qquad \ldots (10)$$

Rate of global insolation,

$$G_c = W \sum_{\ell=0}^{6} A(\ell) Z^{2\ell} \qquad \ldots (11)$$

Rate of direct radiation,

$$I_c = W \sum_{i=0}^{6} A(i) Z^{2i} \qquad \ldots (12)$$

Rate of diffuse radiation,

$$D_c = G_c - I_c \sin \alpha \qquad \ldots (13)$$

The weighting factor, W, allows for changes in the intensity of solar radiation due to variations in the distance of the sun from each particular location on the earth. This factor will be defined later. The model also provides a formula for calculating the average daily global insolation. This formula consists of a Fourier series in which the arguments of the trigonometric terms are functions of the day of the year and the Fourier coefficients are functions of the latitude. Thus:

$$G = W \left[ \sum_{j=0}^{4} C(j) \cos (jT) + \sum_{j=5}^{7} C(j) \sin((j - 4)T) \right] \qquad \ldots (14)$$

where the C(j) values are given by:

$$C(j) = \sum_{i=1}^{4} c(i,j) X^{i} \qquad \ldots (15)$$

and:

$$X = (\phi - 12.5)/7.5 \qquad \ldots (16)$$

Goldberg and Klein {8} combined the effective air **mass**, m*, for the day, the opacity plus albedo effects and a correction factor for average cloud cover to estimate the daily global insolation. Their equation was:

$$G = (H_0/2)\left[(1 + \exp(- m^*R))\exp(- m^*(\alpha_0 x + \tau)) + 0.1\right] F_c$$

$$\ldots (17)$$

Reddy {9} introduced a new formula for computing the daily total solar radiation, G, received on the earth's surface;

$$G = k\left[(0.8S + 1)(1 - 0.2t)/\sqrt{\bar{h}}\right] \qquad \ldots (18)$$

$$k = 100(\lambda N + \psi_{i,j} \cos\phi) \qquad \ldots (19)$$

$$\lambda = \left[0.2/(1 + 0.1\phi)\right] \qquad \ldots (20)$$

Only predictions from three of the above models, chosen according to the climatological inputs currently available, will be compared in the present investigation with the measured data. The three models are those of Page {3}, Barbaro et al {6} and a modified Exell model {7}.

## EFFICACY OF THE PREDICTIONS

Because each of the three chosen models uses similar terms in different ways, or uses different parameters, certain modifications had to be made so that the predictions could be properly compared. For the Page model, the behaviour of the measured data which showed a sinusoidal trend, in-phase with solar declination, dictated the following empirical equations for the regression constants:

$$A = 0.315 + 0.0335 \sin\{30(L - 3)\} \qquad (21)$$

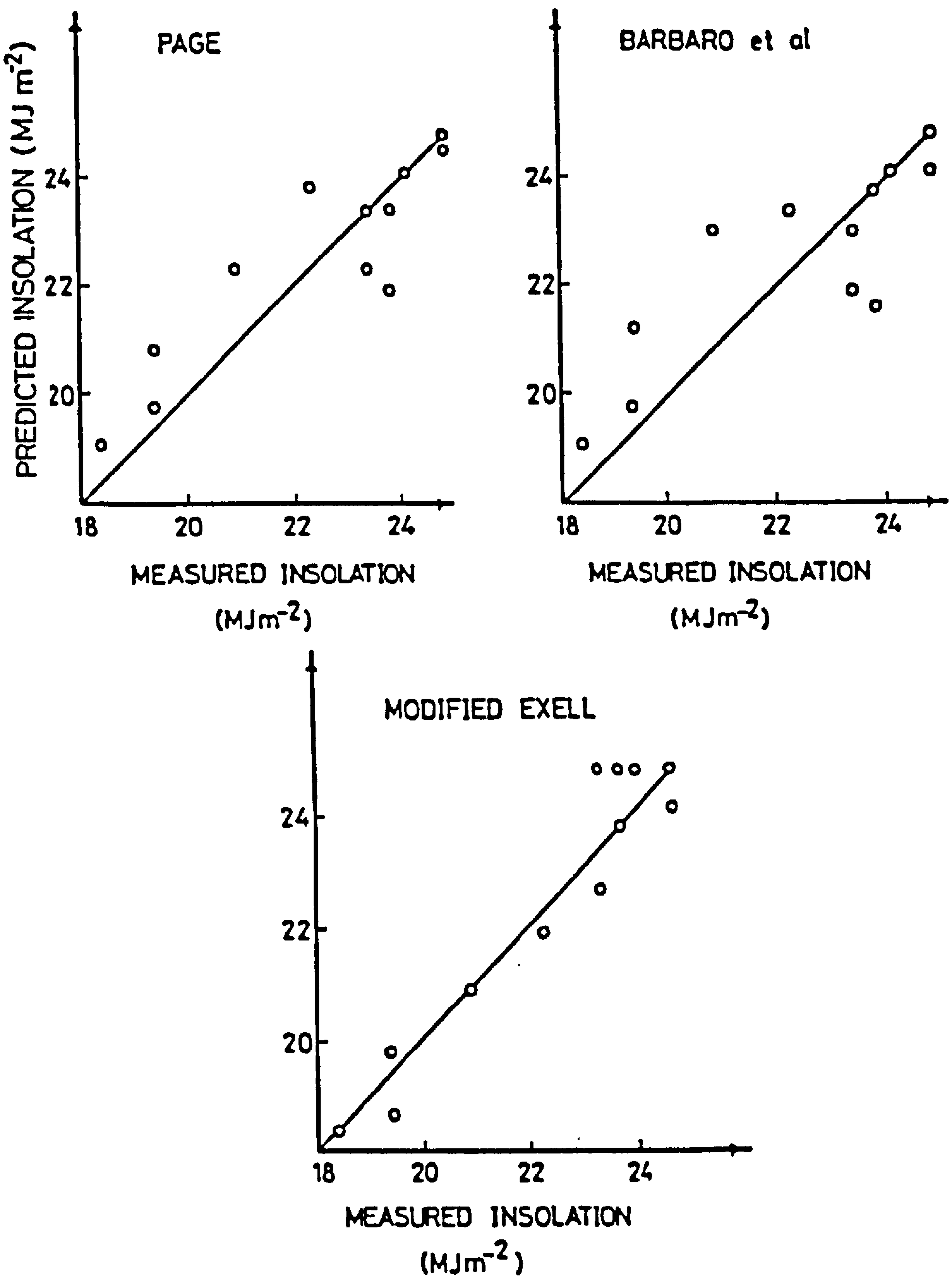


FIG. 3. CORRELATION BETWEEN THE PREDICTED AND MEASURED AVERAGE DAILY TOTAL GLOBAL INSOLATIONS FOR ONE DAY OF EACH MONTH IN SANA'A.

and:

$$B = 0.775 - A \qquad \ldots (22)$$

The parameter $\bar{H}_0$ was estimated from eqn. (2) by selecting for each month the day for which $H_0$ is nearly the same as the mean monthly value (see Table 1).

For the Barbaro et al model {6}, the zone parameter for the latitude range in which the Yemen is located varies sinusoidally according to:

$$K = 15.3 - 0.095 \sin (30(L - 7)) \qquad \ldots (23)$$

The noon altitude was calculated for the same typical day as used to calculate $\bar{H}_0$ in the Page model {3}.

When the behaviour of the measured data for Sana'a was analysed, it indicated that the weighting factor W for the Exell model should be redefined as:

$$W = 0.845 + 0.0115 \sin \{360(y - 196)/365\} \qquad \ldots (24)$$

With these modifications and employing the appropriate equations, the correlations between the predicted and the measured values for the three models were evaluated. The results are shown in Fig. 3 for the average daily global insolations for selected days of the year.

## CONCLUSIONS

As can be seen from Table 2, the percentage deviation reached 9 per cent at maximum for the Page model {3}, 10 per cent for the Barbaro et al model {6} and only 6 per cent for the modified Exell model {7}. Thus the modified Exell empirical formulation (eqn. (4)), gave the best agreement with the measured glabal insolation data. Equations (7) to (14) with W defined by eqn. (24), could therefore be used to:

(i) Estimate the solar radiation intensity to within 6 per cent for the Ibb plain.

TABLE 2

AVERAGE DAILY GLOBAL INSOLATIONS, AS PREDICTED FROM THE AVAILABLE MODELS, TOGETHER WITH THE PERCENTAGE ERRORS RELATIVE TO THE ACTUAL OBSERVATIONS

| Month | Day of the year | Average daily global insolation | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Experimental observation ($MJ\ m^{-2}$) | Page model[3] predicted ($MJ\ m^{-2}$) | Per cent error | Barbaro et al. model[6] predicted ($MJ\ m^{-2}$) | Per cent error | Modified Exell model[7] predicted ($MJ\ m^{-2}$) | Per cent error |
| Jan. | 15 | 19.4 | 19.8 | +2 | 19.8 | +2 | 18.7 | -4 |
| Feb. | 47 | 20.9 | 22.3 | +6 | 23.0 | +9 | 20.9 | 0 |
| March | 74 | 23.4 | 23.4 | 0 | 23.0 | -2 | 22.7 | -3 |
| April | 105 | 24.8 | 24.8 | 0 | 24.8 | 0 | 24.1 | -3 |
| May | 135 | 24.8 | 24.5 | -1 | 24.1 | -3 | 24.8 | 0 |
| June | 166 | 24.1 | 24.1 | 0 | 24.1 | 0 | 24.8 | +3 |
| July | 196 | 23.8 | 21.9 | -9 | 21.6 | -10 | 24.8 | +4 |
| Aug. | 227 | 23.4 | 22.3 | -5 | 21.9 | -7 | 24.8 | +6 |
| Sept. | 258 | 23.8 | 23.4 | -2 | 23.8 | 0 | 23.8 | 0 |
| Oct. | 288 | 22.3 | 23.8 | +6 | 23.4 | +5 | 21.9 | -2 |
| Nov. | 319 | 19.4 | 20.9 | +7 | 21.2 | +9 | 19.8 | +2 |
| Dec. | 349 | 18.4 | 19.1 | +4 | 19.1 | +4 | 18.4 | 0 |

(ii) Provide sensible estimates for the missing data in the station records.

(iii) Establish a typical reference year for solar-energy calculations in the Yemen.

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# C H A P T E R   T H R E E

## THERMAL BEHAVIOURS OF VERNACULAR BUILDINGS IN THE YEMEN ARAB REPUBLIC

## NOMENCLATURE

| | | |
|---|---|---|
| $A$ | Vertical area, in contact with the ambient environment, of the solid walls (i.e. excluding windows) of the house | $m^2$ |
| $A_r$ | External area of the horizontal roof of the considered house | $m^2$ |
| $A_{ref}$ | External area of the reference house roof | $m^2$ |
| $A_{win}$ | Total glazed area for each storey of the considered house | $m^2$ |
| $C_n(j,k)$ | Wall-roof matrix, an expression for which is given by eqn. (18) | |
| $C_{p,i}$ | Specific heat of the material in the ith layer of the vertical wall (or horizontal roof) | $J\ kg^{-1}K^{-1}$ |
| $d_i$ | Thickness of the ith layer (in the vertical wall or horizontal roof) | m |
| $f_r, f_w$ | Ratio of the rate of energy transmitted through a horizontal roof (or vertical wall) to that falling on the horizontal roof (or vertical wall) at a specific time | |
| $F_n$ | U-value of a specified wall: defined for n>1 by equation (20) | $W\ m^{-2}K^{-1}$ |
| $F_{n,I}(j,k), F_{n,II}(j,k)$ | Dimensionless quantities as given by eqns. (65) and (71) respectively | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $g(k), g_n(k)$ | Dimensionless quantities defined by eqns. (49) and (51) respectively | |
| $g_{1,I}(j,k), g_{2,II}(j,k)$ | Dimensionless quantities as defined by eqns. (56) and (58) respectively | |
| $g_{n,I}(j,k), g_{n,II}(j,k)$ | Dimensionless quantities, as given by eqn. (60) | |
| $h$ | Overall (i.e. including radiation contribution) heat loss coefficient | $W\ m^{-2}K^{-1}$ |
| $h_i$ | Air-film heat-transfer coefficient for the inside wall of the considered house as defined in Table 1 | $W\ m^{-2}K^{-1}$ |
| $h_o$ | Air-film heat-transfer coefficient for the outside surface of the considered house evaluated under respectively sheltered, normal, or severe wind conditions (see Table 1) | $W\ m^{-2}K^{-1}$ |
| $h_{o,1}$, $h_{o,n}$ | Outside air-film heat-transfer coefficients for n=1 and n>1 respectively | $W\ m^{-2}K^{-1}$ |
| $H$ | Long-wave rate of thermal radiation from a black surface at the environmental air temperature:average values for typical vertical and horizontal surfaces in the Yemen are given by eqn. (21a) | $W\ m^{-2}$ |
| $j$ | Integer, referring to the design of the chosen roof and its combination of constructional materials; j=1,2,3,.... or 9 as designated in Fig. 2. | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $k$ | Integer, such that $1 \leqslant k \leqslant 10$: it refers to the glazed-to-wall area ratio, see eqns. (14) and (15) | |
| $\ell$ | Integer indicating direction for east, west, north or south, for which $\ell$ equals 1,2,3 or 4 respectively | |
| $l$, $l_r$ | Wall length for the n-storey and reference houses respectively | m |
| $L$ | Insolation period: normally $L = 8$ hours | hr |
| $M_n(j,k)$ | The n-storey house coupling matrix - see eqn. (17) | |
| $n$ | Number of storeys in the considered building | |
| $\dot{q}(t)$ | Instantaneous value of the total heat flux entering a house or (emerging from the house, if its value is of negative sign) as defined by equation (22) | W |
| $\dot{q}_{cg}(t)$ | Transient rate of thermal flux conducted, through the glazed elements, into the house, as defined by eqn. (25) | W |
| $\dot{q}_{dir}(t)$, $\dot{q}_{indr}(t)$ | The direct and indirect heat transfer components of the flux entering the house: these are evaluated respectively at time t in eqns. (23) and (30) | W |
| $\dot{q}_{fe}(t)$ | Transient rate of heat gain from the "free" energy sources within the house | W |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\dot{q}_g(t), \dot{q}_v(t)$ | Rates of thermal loss from the house via the ground and ventilation respectively | W |
| $\bar{\dot{q}}_{indr}$ | 24 hour average of the instantaneous rate of heat transfer through the building structure, as defined by eqn. (31) | W |
| $\tilde{\dot{q}}_{indr}(t')$ | Swing of the heat flow about the daily average of the rate of heat being transferred, through the building structure, to or from the house, as defined by eqn. (34) | W |
| $\dot{q}_{njk,I}(t), \dot{q}_{njk,II}(t)$ | Transient rates of heat loss from a house of n storeys in groups I and II respectively, as defined by eqns. (39) and (40) | W |
| $\dot{q}_T(t)$ | Transient rate of solar energy transmitted through the glazed area into the house, as defined by eqn. (24) | W |
| $\dot{Q}_1$ | Average steady-state (i.e. in practice the mean value over 24 hours) rate of heat loss from the ground storey as indicated by eqn. (11) | W |
| $\sum_{\ell=1}^{4} \dot{Q}_\ell(t)$ | Transient rate of solar energy falling per unit area on the differently oriented (i.e. east, west, north or south facing) house walls | $W\ m^{-2}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\dot{Q}_{n,I}(j,k), \dot{Q}_{n,II}(j,k)$ | Steady-state rates of heat loss from a house of n storeys in groups I and II respectively, as defined by eqns. (16) and (17) | W |
| $\dot{Q}_r, \dot{Q}_w, \dot{Q}_{win}$ | Rates of steady-state heat loss through the roof (and ceiling), walls, and windows respectively: expressions for which are given by eqns. (7), (6), and (8) | W |
| $\dot{Q}_{ref,I}(j,k), \dot{Q}_{ref,II}(J,k)$ | Steady-state rates of heat loss from the reference house of groups I and II respectively, as defined by eqns. (55), and (57) | W |
| R | Ratio of wall length of the n-storey house relative to that of the reference house, as defined by eqn. (53) | |
| $R_{njk,I}(t), R_{njk,II}(t)$ | Heat loss reduction factors, expressions for which are given by eqns. (42) and (43) respectively | |
| $R_t$ | Total thermal resistance of a wall or roof - see eqn. (4) | $W^{-1}m^2\ K$ |
| S | Sum of the vertical outside surface areas of the external solid homogeneous walls for the considered storey | $m^2$ |
| $S_r$ | Solid homogeneous wall area for the considered storey of the reference house | $m^2$ |
| t,t' | Time periods: $t' = t + \phi$ | hr |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $T_e, T_i$ | The average daily temperatures of the ambient environment and of the air inside the house respectively | K |
| $T_o, T_o(t)$ | Ambient environmental air temperatures in the steady-state and transient-state representations respectively | K |
| $T_{sa}(t)$ | Sol-air temperature appropriate to the direction and surface of a wall or roof, as defined by eqn. (21) | K |
| $\bar{T}_{sa,r}, \bar{T}_{sa,w}$ | 24 hour average of the sol-air temperatures appropriate to the direction and surface of the roof and house walls respectively | K |
| $T_{sa,r}(t), T_{sa,w}(t)$ | Instantaneous sol-air temperatures appropriate to the direction and surface of the horizontal roof and house walls respectively | K |
| $T_{sa,r}(t'), T_{sa,w}(t')$ | Sol-air temperature, evaluated at $t'=t+\phi$, appropriate to the direction and surface of the roof and house walls respectively | K |
| U | Composite wall heat transfer coefficient, see eqn. (2) | $W\ m^{-2}K^{-1}$ |
| $U_{cr}$ | Composite roof heat transfer coefficient, see eqn. (7) | $W\ m^{-2}K^{-1}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $U_{cr,j}$ | Heat transfer coefficient for the jth type of roof construction (see Fig. 2) | W m$^{-2}$K$^{-1}$ |
| $U_1, U_2$ | Heat transfer coefficients for the first and the second storeys respectively of groups I and II houses | W m$^{-2}$K$^{-1}$ |
| $U_{n,I}, U_{n,II}$ | Heat transfer coefficients for the nth storey houses in groups I and II respectively, expressions for which are given by eqns. (12) and (13) | W m$^{-2}$K$^{-1}$ |
| $U_{n,I}(j,k), U_{n,II}(j,k)$ | Heat transfer coefficients for groups I and II houses respectively, as defined by eqns. (61) and (62) | W m$^{-2}$K$^{-1}$ |
| $v$ | Mean wind speed to which the external wall is exposed (see Table 1) | m s$^{-1}$ |
| $x_i$ | Thickness of the ith vertical structural layer in the wall | m |
| $z$ | Integer, z=1 to 8; refers to the type of wall construction as designated in Fig. 3 | |
| $\alpha$ | Absorption coefficient of the materials of the outer wall or roof surfaces respectively for short-wave radiation - see references 1 and 2 | |
| $\alpha_g$ | Absorption coefficient for glass; for the present numerical predictions, it is assumed that $\alpha_g = 0.2$ | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\varepsilon$ | Emissivity of the outer surface considered - see Table 1 | |
| $\eta$ | Dimensionless constructional parameter defined by equation (54) | |
| $\eta_g(t)$ | Dimensionless parameter as defined by eqn. (38) | |
| $\eta_r(t), \eta_w(t)$ | Dimensionless parameters, as defined for the roof and walls by eqns. (37) and (36) respectively | |
| $\theta_o$ | Initial temperature of the outer surface of the external wall | K |
| $\theta(t)$ | Temperature at a general point in the external wall, as given by eqn. (27) | K |
| $\lambda_i$ | Thermal conductivity of the ith layer in the vertical wall (or horizontal roof) | $W\ m^{-1}K^{-1}$ |
| $\mu_i(x)$ | Attenuation factor for the ith vertical structural layer in the wall: see eqn. (28) | |
| $\rho_i$ | Density of the ith layer in the vertical wall (or horizontal roof) | $kg\ m^{-3}$ |
| $\bar{\tau}$ | Glass transmission coefficient: for the numerical predictions, it is assumed that $\bar{T} = 0.85$ | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\phi$ | Phase lag of the temperature signal dependent on the wall (or roof) thickness - see Fig. 4 | hr |
| $\phi_i(x)$ | Phase lag imposed upon the temperature signal due to its passage through the ith vertical structural layer of the wall: see eqn. (29) | hr |

### Suffixes

| | |
|---|---|
| r | of the roof |
| w | of the wall |

# CHAPTER 3

## THERMAL BEHAVIOURS OF VERNACULAR BUILDINGS IN THE YEMEN ARAB REPUBLIC

### Mathematical Model of the Steady-State Heat Transfer Behaviour

The walls, any insulant that is present and the air boundary-layer films associated with a building structure, each offer resistances to heat flows. The steady-state heat transfer equation for the double layer wall (or roof), as represented in Figure 1, is given by the well-known equation:

$$(T_i - T_o) = \dot{Q} \quad \left((1/A\ h_i) + (1/A\ h_o) + (1/A) \sum_{i=1}^{2} d_i/\lambda_i\right) \qquad \ldots (1)$$

However, the overall steady-state heat-transfer coefficient is defined by:

$$\dot{Q} = U\ A\ \Delta T \qquad \ldots (2)$$

where $\Delta T = T_i - T_o$

So

$$U^{-1} = \left(h_i^{-1} + h_o^{-1} + \sum_i d_i/\lambda_i\right) \qquad \ldots (3)$$

Thus for a vertical wall (or horizontal roof) of i parallel vertical (or horizontal respectively) layers, the overall thermal resistance, $R_t$, can be calculated via

$$R_t = \left(h_i^{-1} + h_o^{-1} + \sum_i d_i/\lambda_i\right) \qquad \ldots (4)$$

The total rate of heat loss from a house is the net result of the simultaneous contributions through its walls, roof, floors and windows, and via ventilation.

Houses in the Yemen can be categorised as follows:

Group I: Those with all their external walls of the same material, irrespective of the number of storeys.

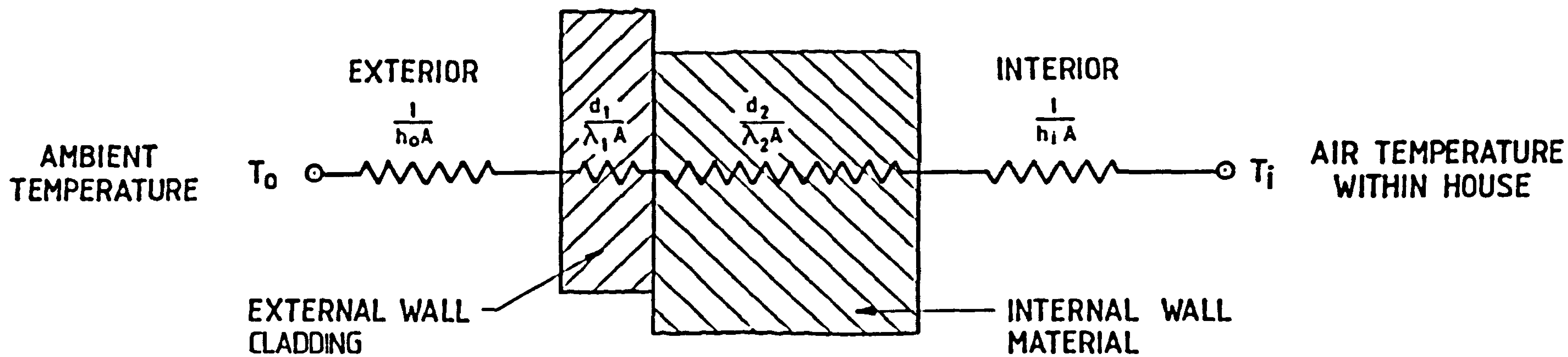



FIG. 1 THERMAL RESISTANCE CIRCUIT FOR THE STEADY-STATE HEAT LEAKS THROUGH THE TWO-LAYER BOUNDARY ELEMENTS OF A HOUSE.

Group II: Those built with external walls of different materials for each storey.

In order to obtain a first approximate description of the thermal performance of a house, it is assumed that:-

i) its internal temperature can be assigned a single value $T_i$;

ii) the heat losses via ventilation and to the ground are balanced by heat gains from its occupants, solar energy and/or interior lighting;

iii) the heat capacity of the building structure has no effect on the thermal performance, i.e. steady-state behaviour is considered.

Thus the total rate of heat loss from the building is given by:

$$\dot{Q} = \dot{Q}_w + \dot{Q}_r + \dot{Q}_{win} \qquad \dots (5)$$

where

$$\dot{Q}_w = (S_1 U_1 + S_2 U_2 + \dots\dots\dots\dots + S_n U_n) \Delta T \qquad \dots (6)$$

$$\dot{Q}_r = A_r U_{cr} \Delta T \qquad \dots (7)$$

and

$$\dot{Q}_{win} = n A_{win} U_{win} \Delta T \qquad \dots (8)$$

For Group I houses

$$\dot{Q}_w = n U_1 S \Delta T \qquad \dots (9)$$

where n is the number of storeys in the considered house.

Combining equations 7, 8 and 9, and substituting into an equation corresponding to (5), gives

$$\dot{Q}_{n,I} = \left(n + \frac{A_r\, U_{cr}}{S\, U_1} + n \quad \frac{A_{win}\, U_{win}}{S\, U_1}\right) \dot{Q}_1 \qquad \ldots (10)$$

where $\dot{Q}_1$ is the steady-state rate of heat loss through the walls of the first storey, defined in terms of the corresponding heat transfer coefficient by:

$$\dot{Q}_1 = S\, U_1 \quad T \qquad \ldots (11)$$

There will be a greater effect of wind assault on the rate of heat loss from the upper storeys than from the lower ones. The overall heat transfer coefficient for the nth storey can be expressed in terms of that for the first storey. These two heat transfer coefficients differ in the value of $h_o$ for Group I houses and in the values of $h_o$ and thermal conductivity-thickness ratio for Group II houses. Accounting for the exposure of the external walls and roof to the wind, see Table 1, and using eqn. (3) we can deduce that:

<u>For Group I houses</u>

$$U_{n,I} = \left(h_{o,n}/h_{o,1}\right)\left(\frac{h_i + h_{o,1} + h_i h_{o,1} \sum_i d_i/\lambda_i}{h_i + h_{o,n} + h_i h_{o,n} \sum_i (d_i/\lambda_i)}\right) U_1 \qquad \ldots (12)$$

<u>For Group II houses</u>

$$U_{n,II} = \left(h_{o,n}/h_{o,1}\right) \left(\frac{h_i + h_{o,1} + h_i\, h_{o,1} \sum_i (d_i/\lambda_i)_{n=1}}{h_i + h_{o,n} + h_i\, h_{o,n} \sum_i (d_i/\lambda_i)_{n>1}}\right) U_1 \qquad \ldots (13)$$

Traditionally, Yemenis tend to occupy dwellings with the following design ratios {3}:-

$$A_r/S = 0.05k\ (K + 0.5) \qquad \ldots (14)$$

$$A_{win}/S = 0.05k \qquad \ldots (15)$$

where $k$ = an integer, such that $1 \leqslant k \leqslant 10$

TABLE 1

INTERNAL AND EXTERNAL HEAT-TRANSFER COEFFICIENTS {1,2}

| Building element | Value of the surface emissivity $\varepsilon$ used in the predictions | Heat transfer coefficient ($W\ m^{-2}K^{-1}$) | | | |
|---|---|---|---|---|---|
| | | For internal (i.e. facing human-habitation zone) surface $h_i$ | For ambient environment surface, suffering wind assault $h_o$ | | |
| | | | sheltered ($0<v<2m\ s^{-1}$) | normal ($2m\ s^{-1}<v<4m\ s^{-1}$) | severe ($4m\ s^{-1}<v<14m\ s^{-1}$) |
| Walls | high:0.90 | 8.13 | 12.5 | 18.2 | 34.4 |
| | low :0.05 | 3.29 | 9.1 | 14.9 | 30.9 |
| Roof/Ceilings | high:0.90 | 9.43 | 14.3 | 22.2 | 47.5 |
| | low :0.05 | 4.59 | 11.1 | 18.9 | 43.7 |

For the jth type of roof (as defined in Fig. 2), and using equations (10), (14) and (15), it can be deduced that

$$\dot{Q}_{n,I}(j,k) = \left[n + 0.5k(k + 0.5)\left(U_{cr,j}/U_1\right) + 0.05kn\left(U_{win}/U_1\right)\right] \dot{Q}_1$$

or

$$\dot{Q}_{n,I}(j,k) = M_n(j,k)\ \dot{Q}_1 \qquad \text{... (16)}$$

where the matrix $M_n(j,k)$ indicates the influence of the wall-roof combination on the total steady-state rate of heat loss from the house, and is given by

$$M_n(j,k) = n + C_n\ (j,k) \qquad \text{... (17)}$$

where

$$C_n(j,k) = \left[0.05k\ (k + 0.5)(U_{cr,j}/U_1) + 0.05kn\ (U_{win}/U_1)\right] \qquad \text{... (18)}$$

A similar procedure can be used for Group II houses, i.e.

$$\dot{Q}_{n,II}(j,k) = \left[M_n(j,k) + (F_n/U_1) + (1 - n)\right]\ \dot{Q}_1 \qquad \text{... (19)}$$

where $F_n$ is the sum of the U-factors for the different walls, i.e.

$$F_n = \sum_{z=2}^{n} U_z \qquad \text{... (20)}$$

Justification for Employing the Steady-State Approach

The diurnal variations of the ambient environment's temperature and the insolation upon house walls are not accounted for in equations (16) and (19). A more rigorous approach would allow for the transient behaviour taking into account the thermal inertia of the walls and roof, and the variations of the ambient temperature and the energy inputs as functions of time. The usual practice {1,5} under such conditions, is to express the rate of heat transfer, i.e. the amount of flux entering (or emerging

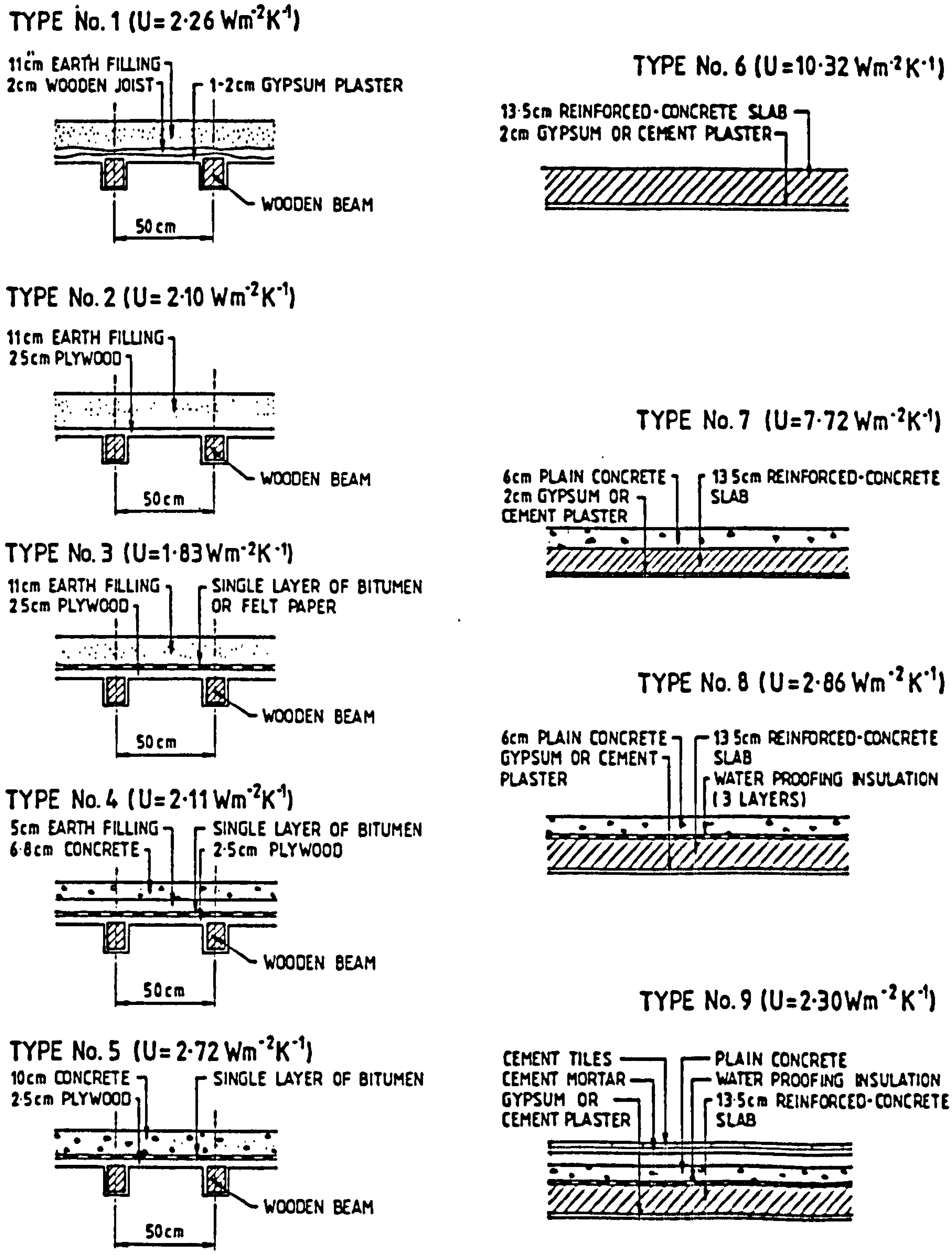



FIG. 2. VERTICAL CROSS-SECTIONS OF TRADITIONALLY-EMPLOYED HORIZONTAL ROOFS ON DWELLINGS IN THE YEMEN ARAB REPUBLIC.

from) the house, in terms of the differences between the artificial environmental and the sol-air temperatures rather than on the inside-outside air temperature difference. This tactic {1} simplifies certain calculations, and moreover the artificial environmental temperature, $T_e$, is a better index for human comfort assessment purposes than the inside air temperature, $T_i(t)$. In this analysis, we fix $T_e$ at the comfort level of 22°C, and calculate the sol-air temperature, $T_{sa}(t)$, appropriate to the direction and surface of the house walls and roof according to:-

$$T_{sa}(t) = \left(T_o(t) + (\alpha\, \dot{Q}_\ell(t) - \varepsilon H)/h\right) \qquad \ldots (21)$$

The parameter H in equation (21) accounts for the long-wave radiation from a black surface at the environmental air temperature. For vertical and horizontal surfaces in the Yemen it is assumed that {1} :

$$\left.\begin{array}{lll} H = 100 \text{ W m}^{-2} & & \text{for a horizontal roof} \\ \text{and} & & \\ H = 0 & & \text{for vertical walls} \end{array}\right\} \qquad \ldots (21a)$$

The total heat flux entering the house, can be described by the following general equation:

$$\dot{q}(t) = \dot{q}_{dir}(t) + \dot{q}_{indr}(t) \qquad \ldots (22)$$

where $\dot{q}_{dir}(t)$ and $\dot{q}_{indr}(t)$ represent respectively the contributions of the direct and indirect heat transfer components to the flux.

The value of $\dot{q}_{dir}(t)$ results from contributions due to the:-

- transient rate of solar energy transmitted through the glazed area into the house, $\dot{q}_T(t)$;
- transient rate of thermal fluxes conducted, through the glazed area, into the house, $\dot{q}_{cg}(t)$;
- rate of ventilation heat losses, resulting from the changes of the inside air, $\dot{q}_v(t)$;

- rate of heat gains from the free energy sources within the house, $\dot{q}_{fe}(t)$; and

- rate of thermal losses through the floor, $\dot{q}_g(t)$.

Accordingly $\dot{q}_{dir}(t)$ is the appropriate sum of all these terms, i.e.

$$\dot{q}_{dir}(t) = \dot{q}_T(t) + \dot{q}_{fe}(t) + \dot{q}_{cg}(t) - \dot{q}_v(t) - \dot{q}_g(t) \qquad \ldots (23)$$

Assuming that the heat losses to the ground and due to ventilation are balanced by the rate of heat gains from the "free" energy sources including those within the house, then equation (23) can be rewritten in the form:

$$\dot{q}_{dir}(t) = \dot{q}_T(t) + \dot{q}_{cg}(t)$$

where

$$\dot{q}_T(t) = \bar{\tau} \sum_{\ell=1}^{4} A_{win} \; \dot{Q}_\ell(t) \qquad \ldots (24)$$

and

$$\dot{q}_{cg}(t) = U_{win} A_{win} \, (T_{sa}(t) - T_e) \qquad \ldots (25)$$

On the other hand, the contribution of the indirect components, $\dot{q}_{indr}(t)$, instantaneous at a time, to the flux entering or emerging from the house occurs at some later time, t' (= t + $\phi$).

This delay depends on the thickness and density of the boundary walls and roof.

Let us consider the response of the indoor temperature to any incident solar heat gains. The general equation for the one-dimensional heat flow through a wall is

$$\frac{\partial^2 \theta(t)}{\partial x^2} = \left(\frac{\rho \, C_p}{\lambda}\right) \frac{\partial \, \theta(t)}{\partial t} \qquad \ldots (26)$$

During the insolation period, L, the temperature at a general point, of co-ordinate x, in the wall can be written {4} as:

$$\theta(t) = \left(\mu(x)\ \theta_o\right)\ \sin\left[\left(2\pi(t - \phi(x)\right)\ /24\right] \qquad \ldots (27)$$

where $\mu(x)$ and $\phi(x)$ are respectively the attenuation factor and time delay for a heat pulse propagating through the wall.

On substituting from equation (27) into equation (26), the following expressions can be deduced for the effects of ith vertical layer of the considered wall:-

$$\mu_i(x) = \exp\left\{ -\left(\sqrt{\frac{\pi\ \rho_i\ C_{p,i}\ \lambda_i}{L}}\right)\ (x_i/\lambda_i)\right\} \qquad \ldots (28)$$

and

$$\phi_i(x) = (L/120)\ \left(\sqrt{\frac{\rho_i\ C_{p,i}\ \lambda_i}{\pi L}}\right)(x_i/\lambda_i) \qquad \ldots (29)$$

Wall types 6, 7 and 8 (see Fig. 3) are used only as the walls of ground storeys in the modern multi-storey houses. A vernacular multi-storey house can be built wholly using any of types 1 to 5. However, if dissimilar types are used for each storey, they are constructed traditionally with stone (type 1) for the ground-floor walls, followed by concrete (type 3), brick (type 2), or mud (type 4) for successively higher storeys in decreasing order of popularity. Reinforced concrete walls (type 5) are used for the top storeys in buildings of up to three storeys in height, for which the lower storeys have concrete or stone walls.

It can be deduced (via equations 28 and 29 and using the data presented in Table 2) for buildings with vernacular walls (of types 1 or 4), that thermal comfort is maintained better within the structure during the summer months than is achieved with commonly-adopted modern structures (of type 3 for example).

Such predictions are corroborated by experience. The plot of $\phi_i(x)$ as a function of x, is shown in Fig. 4. The phase lags between the attainment of maximum temperatures at the outer and inner surfaces of a wall will

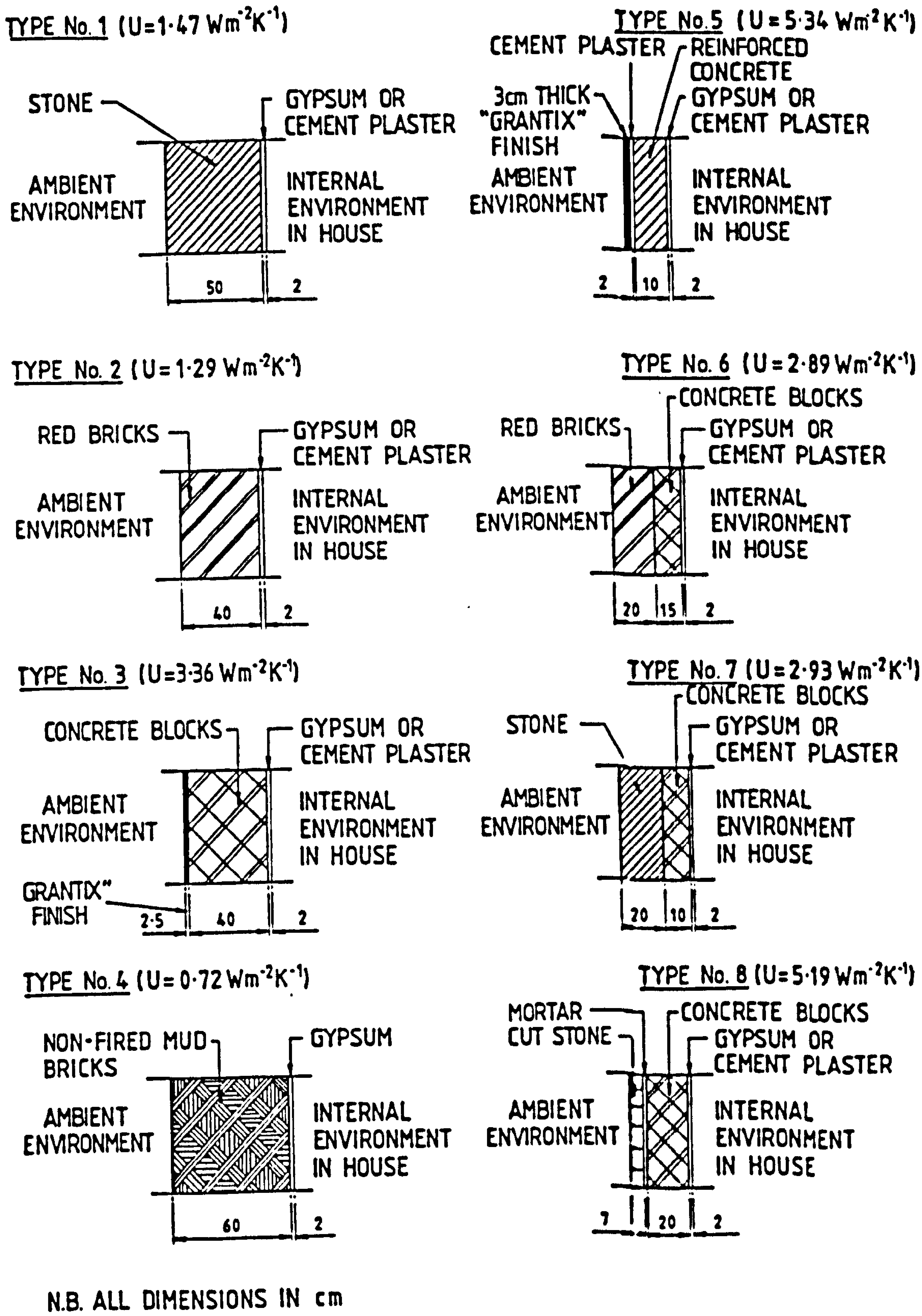



FIG. 3 VERTICAL CROSS-SECTIONS OF SOME COMMONLY-EMPLOYED TYPES OF WALLS IN THE YEMEN ARAB REPUBLIC.

TABLE 2

PHYSICAL PROPERTIES OF SOME COMMONLY-USED WALLS OF BUILDINGS IN THE YEMEN

| Wall type - see Fig. 3 | $\rho_i$ $(Mg\ m^{-3})$ | $d_i$ ( m ) | $C_{p,i}$ $(J\ kg^{-1}\ K^{-1})$ | $\lambda_i$ $(W\ m^{-1}\ K^{-1})$ |
|---|---|---|---|---|
| 1 | 2.72 | 0.52 | 877 | 0.872 |
| 2 | 2.24 | 0.42 | 836 | 0.601 |
| 3 | 2.21 | 0.45 | 897 | 1.745 |
| 4 | 1.84 | 0.62 | 753 | 0.465 |

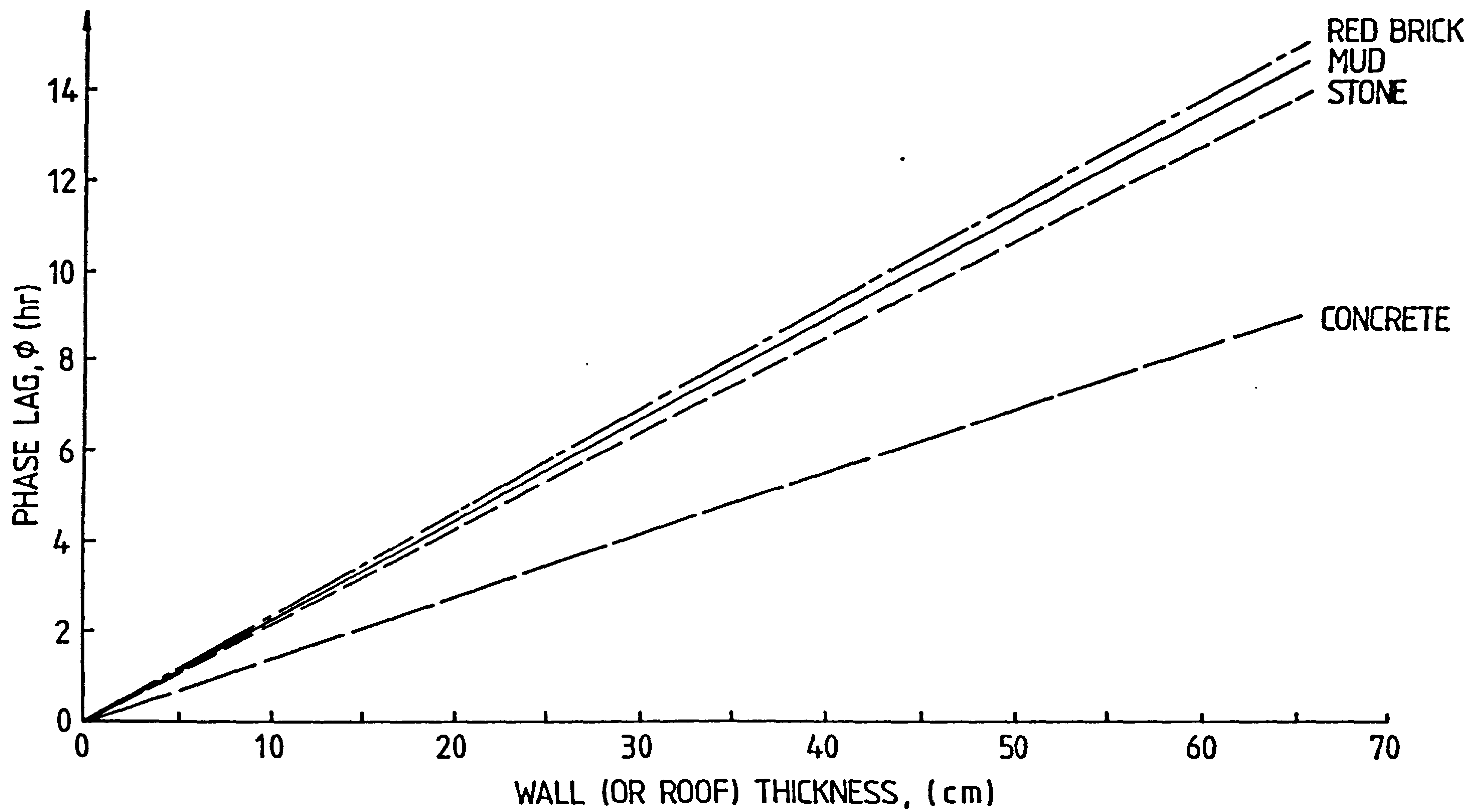



FIG. 4 PHASE-LAGS FOR A THERMAL SIGNAL PASSING THROUGH DIFFERENT THICKNESS OF THE STATED WALL MATERIALS

be approximately 15 hours for types 1 and 4 walls, and between 9 and 14 hours for all other types considered here. Because the phase lag, $\phi$, evaluated at $x > 0.4$m, for all the materials considered except concrete is greater than the eight hour insolation period, the contribution of the stored solar gains, (i.e. the indirect heat transfer components $\dot{q}_{indr}(t)$), is negligible during that period for almost all the walls considered. Several methods have been used to estimate the contribution of the indirect heat transfer components to the flux entering or emerging from the house. The method followed here expresses such contributions as the sum of the daily average of the instantaneous rate of heat transfer through the solid elements of the house and the swing of the heat flow, evaluated at time $t' = t + \phi$, where $\phi$ is the phase lag. Thus;

$$\dot{q}_{indr}(t) = \bar{\dot{q}}_{indr} + \tilde{\dot{q}}_{indr}(t') \qquad \ldots (30)$$

The average daily rate of heat transfer {5} through the solid elements of a house is given by:

$$\bar{\dot{q}}_{indr} = U\,S(\bar{T}_{sa,w} - T_e) + U_{cr}\,A_r\,(\bar{T}_{sa,r} - T_e) \qquad \ldots (31)$$

where $\bar{T}_{sa,w}$, $\bar{T}_{sa,r}$ and $T_e$ are respectively the 24 hour average values of the sol-air temperatures, appropriate to the direction and surface of the house walls and roof, and the constant indoor environmental temperature.

If the thermal capacity of the roof or the wall were infinite and there were no fluctuations of temperature but simply a steady temperature-difference existed, then the rate of heat transfer to the house walls would be given by equation (31). However, if the thermal capacity were zero, the rate of heat transfer at time t would be:

$$\dot{q}_{indr}(t) = U\,S\,(T_{sa,w}(t) - T_e) + U_{cr}\,A_r\,(T_{sa,r}(t) - T_e) \qquad \ldots (32)$$

The actual rate of heat transfer into the house, $\dot{q}_{indr}(t)$, lies somewhere between the extreme values shown by equations (31) and (32), and this occurs at some later time, $t' = t + \phi$. This rate is calculated by adding to the expression given by equation (31) the swing of the heat flow about the mean evaluated at time $t' = t + \phi$. Thus

$$\dot{q}_{indr}(t) = \bar{\dot{q}}_{indr} + \tilde{\dot{q}}_{indr}(t') \qquad \ldots (33)$$

where

$\bar{\dot{q}}_{indr}$ is given by equation (31) and $\tilde{q}_{indr}(t')$ is given by { 1 }:

$$\tilde{\dot{q}}_{indr}(t') = f_w\, U\, S\left(T_{sa,w}(t') - T_e\right) + f_r\, U_{cr} A_r \left(T_{sa,r}(t') - T_e\right) \qquad \ldots (34)$$

where $f_w$ and $f_r$ are the decrement factors respectively of the house walls and roof, and dependent on their respective thicknesses; and $T_{sa,w}(t')$ and $T_{sa,r}(t')$ are respectively the sol-air temperatures at $t' = t + \phi$, appropriate to the direction and surface of the house walls and roof.

The overall rate of heat transfer, $\dot{q}(t)$, can be obtained as the sum of components described by equations (33) and (23), i.e.,

$$\dot{q}(t) = U\, S\left(T_e - T_o(t)\right)\left(\eta_w(t) + (U_{cr}A_r/U\, S)\eta_r(t) - (U_{win}A_{win}/U\, S)\eta_g(t)\right) \qquad \ldots (35)$$

where $\eta_w(t)$, $\eta_r(t)$ are dimensionless parameters expressing the ratio of the temperature difference, as evaluated at times t' and t, between the indoor environmental temperature and the ambient sol-air temperature, and $\eta_g(t)$ is a dimensionless parameter expressing the instantaneous effect of the direct heat transfer components on the indoor climate. Expressions for these are:-

$$\eta_w(t) = \left(\bar{T}_{sa,w} + f_w\, T_{sa,w}(t') - (1 + f_w)T_e\right)\Big/\left(T_e - T_o(t)\right) \qquad \ldots (36)$$

$$\eta_r(t) = \left(\bar{T}_{sa,r} + f_r\, T_{sa,r}(t') - (1 + f_r)T_e\right)\Big/\left(T_e - T_o(t)\right) \qquad \ldots (37)$$

$$\eta_g(t) = \left(1 - \frac{(\bar{\tau}\, h + \alpha_g\, U_{win}) \sum_{\ell=1}^{4} \dot{Q}_\ell(t)}{h\, U_{win}\left(T_e - T_o(t)\right)}\right) \qquad \ldots (38)$$

Equation (35) can be generalised to permit one to obtain descriptions of the behaviours of all walls and roofs employed in the Yemeni houses as follows:

For a n-storey house in Group I:

$$\dot{q}_{njk,I}(t) = U_1S\Big(T_e - T_o(t)\Big)\Big( n\,\eta_w(t) + (U_{cr,j}\ A_r/U_1S)\ \eta_r(t) - n(U_{win}A_{win}/U_1S)\eta_g(t)\Big) \qquad \ldots (39)$$

For a n-storey house in Group II:

$$\dot{q}_{njk,II}(t) = U_1S(T_e - T_o(t))\Big(\Big(1+(F_n/U_1)\Big)\eta_w(t)+(U_{cr,j}\ A_r/U_1S)\eta_r(t) - n(U_{win}A_{win}/U_1S)\eta_g(t)\Big) \qquad \ldots (40)$$

Using equations (16), (19), (39) and (40), we can devise the following general expressions

$$\dot{q}_{njk,I}(t) = R_{njk,I}(t)\ \dot{Q}_{n,I}(j,k)$$

and

$$\dot{q}_{njk,II}(t) = R_{njk,II}(t)\ \dot{Q}_{n,II}(j,k) \qquad \ldots (41)$$

where

$$R_{njk,I}(t) = (\Delta T(t)/\Delta T)\left(1 - \frac{n\Big(1-\eta_w(t)\Big)+0.05k(k+0.5)\Big(1-\eta_r(t)\Big)\Big(U_{cr,j}/U_1\Big)+0.05kn\Big(1+\eta_g(t)\Big)\Big(U_{win}/U_1\Big)}{M_n(j,k)}\right) \qquad \ldots (42)$$

and

$$R_{njk,II}(t) =$$

$$(\Delta T(t)/\Delta T)\left(1 - \frac{\left(1-\eta_w(t)\right)\left(1+(F_n/U_1)\right)+0.05k(k+0.5)\left(1-\eta_r(t)\right)\left(U_{cr,j}/U_1\right)+0.05kn\left(1+\eta_g(t)\right)\left(U_{win}/U_1\right)}{\left(M_n(j,k)+(F_n/U_1)+(1-n)\right)}\right) \quad \cdots (43)$$

where $\Delta T(t) = T_e - T_o(t)$; $\Delta T = T_i - T_o$

The heat reduction factor ($R_{njk}(t)$, depending on the time of the day, can be positive, i.e. when heat flows from the house inside to the ambient environment $T_i(t) > T_o(t)$, or negative, i.e. when heat flows in the reverse direction as $T_o(t) > T_i(t)$. In general, according to equations (42) and (43):

$$\left.\begin{array}{l} \underline{\text{for } T_o(t) < T_i(t)} \\ R_{njk,I}(t) > 0 \\ \\ R_{njk,II}(t) > 0 \\ \\ \text{and} \\ \\ \underline{\text{for } T_o(t) > T_i(t)} \\ R_{njk,I}(t) < 0 \\ \\ R_{njk,II}(t) < 0 \end{array}\right\} \quad \ldots (44)$$

Thus the steady-state equations proposed in this model can be used to predict the transient state of heat loss for that period of the day during which the heat flow is from the inside to the outside, i.e. for which $T_o(t) < T_i(t)$. For the period when $T_o(t) > T_i(t)$, which amounts to about 4 hours per day in the summer and to about 2 hours per day in the winter, (see Fig. 5), the temperature

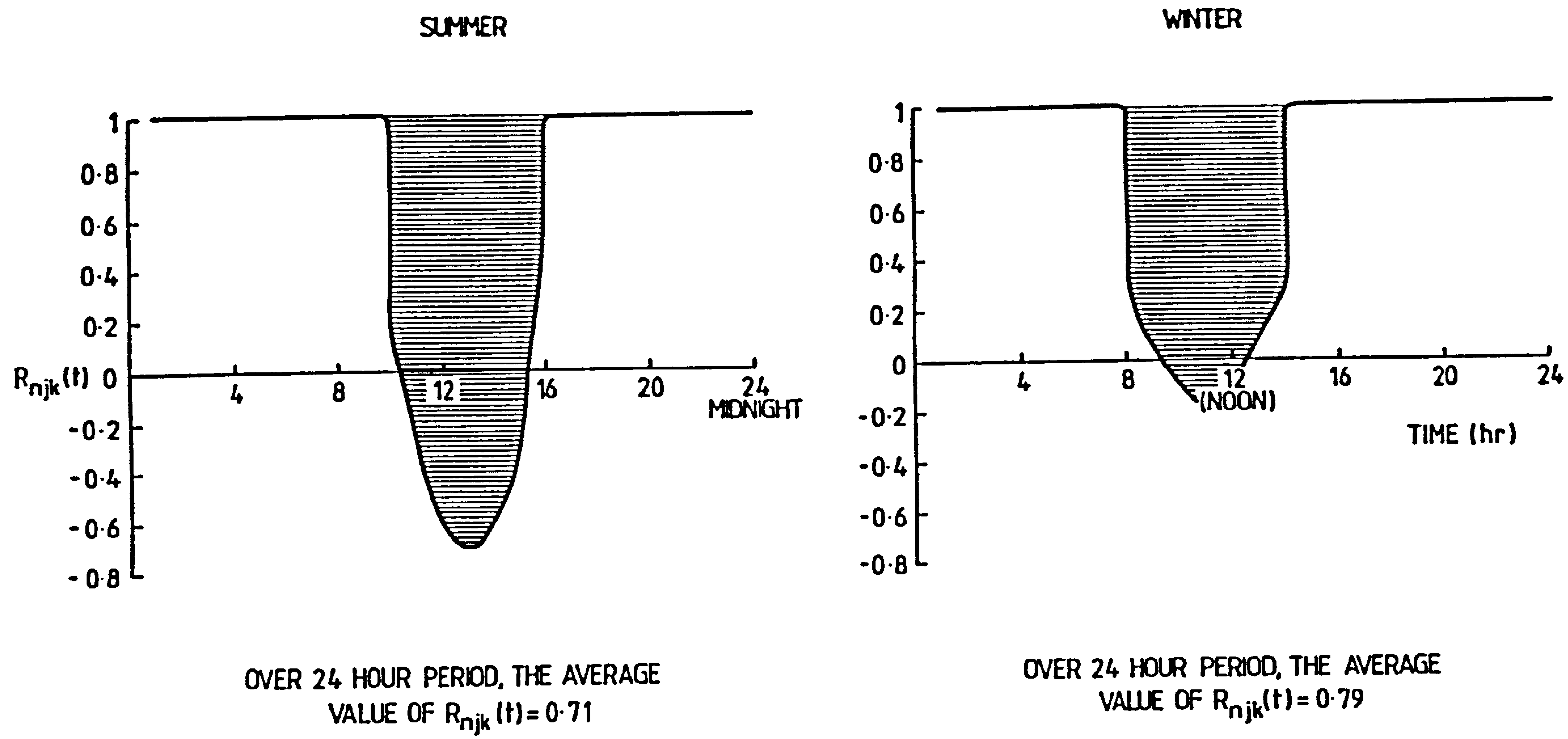



FIG. 5 EXPERIMENTAL OBSERVATIONS OF THE HEAT-LOSS REDUCTION FACTOR AS A FUNCTION OF TIME FOR A TYPICAL YEMENI BUILDING.

distribution in the external wall is affected by the rates of absorption at the external surfaces {6} and consequently the contribution of the stored heat to the increase of the internal house temperature should be included. The experimental observations of the heat loss reduction factor, $R_{njk,I}(t)$, as a function of time for a typical Yemeni house is shown for representative summer and winter days in Fig.5. The plot is for a single -storey stone house with the following design characteristics: a glazed-to-solid wall area ratio of 0.25, a roof U-value of 2.26 $W/m^2K$ and a window U-value of 4.3 $W/m^2K$ for the temperature conditions $\Delta T = 6^{\circ}C$ in winter and $2^{\circ}C$ in summer, and $\Delta T(t) = 22 - T_0(t)$. As shown in Fig. 5, the steady-state and transient rates of heat loss, see equation (41), are equal during the off-sunshine hours. The same agreement was also obtained during the early morning sunshine hours (i.e. 6.00 to 8.00 a.m. in the summer and 7.00 to 8.00 a.m. in the winter), and the late afternoon hours (i.e. 4.00 p.m. to 6.00 p.m. in the summer and 2.00 to 5.00 p.m. in the winter). Thus the total number of hours during which the predictions of the steady-state model agree with those of a transient-state model is, see Fig. 5, 17 hours in the summer and 19 hours in the winter. In other words, the ratio of the shaded area in Fig. 5, i.e. for periods during which the model fails to predict the thermal behaviour of the house, to the unshaded area (i.e. for the periods during which the model is able to predict the thermal behaviour of the house), equals approximately 0.79 for winter and 0.71 for summer. This means that the transient rates of heat loss can be expressed approximately in terms of the steady-state rates of heat loss for both summer and winter as follows:-

<u>For Summer</u>

$$\begin{pmatrix} \dot{q}_{njk,I}(t) \\ \\ \dot{q}_{njk,II}(t) \end{pmatrix} = 0.71 \begin{pmatrix} \dot{Q}_{n,I}(j,k) \\ \\ \dot{Q}_{n,II}(j,k) \end{pmatrix} \quad \ldots (45)$$

For Winter:

$$\begin{pmatrix} \dot{q}_{njk,I}(t) \\ \\ \dot{q}_{njk,II}(t) \end{pmatrix} = 0.79 \begin{pmatrix} \dot{Q}_{n,I}(j,k) \\ \\ \dot{Q}_{n,II}(j,k) \end{pmatrix} \qquad \ldots (46)$$

APPLICATION OF THE MODEL

The performances of different houses have been assessed relative to a reference house. For Group I houses (i.e. those built of a single material), the reference house has only a single storey. However, for Group II houses (i.e. those built of more than one material), the reference house is two storeys high. The selection of a two-storey house as the "base" system for Group II allows for a change in materials of construction for each storey. Two cases are of practical interest.

The first is that in which the design of each storey of the nth storey house is an exact duplicate of that of the chosen reference house, i.e. the design as well as the building materials are the same for both houses. For such a case:

$$\left.\begin{array}{l} \dot{Q}_{ref,I}(j,k) = \dot{Q}_{1,I}(j,k) \\ \\ \text{and} \\ \\ \dot{Q}_{ref,II}(j,k) = \dot{Q}_{2,II}(j,k) \end{array}\right\} \qquad \ldots (47)$$

From equations (16) and (19) it can be shown that:

$$\dot{Q}_{n,I}(j,k) - \dot{Q}_{1,I}(j,k) = (n - 1)\, \dot{Q}_1 g(k) \qquad \ldots (48)$$

where

$$g(k) = \left(1 + 0.05k\left(U_{win}/U_1\right)\right) \qquad \ldots (49)$$

and

$$\dot{Q}_{n,II}(j,k) - \dot{Q}_{2,II}(j,k) = g_n(k)\,\dot{Q}_1 \qquad \ldots (50)$$

where

$$g_n(k) = \left\{(n-2)\,(g(k)-1) + \left[\left(F_n - U_2\right)/U_1\right]\right\} \qquad \ldots (51)$$

For the <u>second</u> case, the design of the n-storey house differs from that of the reference house. For example, the roof area of the n-storey house, assuming the same roof area for each storey, is greater than that of the reference house. To evaluate the contribution which such a change will have upon the rate of heat loss using the present model, it is necessary to relate the wall/roof area of the nth-storey house to that of the reference house. In Yemeni buildings the roof width is usually fixed, but the length does vary according to the size of the available plot of land. The solid wall's vertical area as well as the roof's horizontal area, of the n-storey house can be related to the corresponding values for the reference house as follows:

$$S_r = (\eta/R) \quad \text{and} \quad A_{ref} = (A_r/R) \qquad \ldots (52)$$

where R and $\eta$ are the appropriate ratios of the length of the wall or roof of each storey of the house of n-storeys to those of the reference house, i.e.

$$R = (1/1_r) \qquad \ldots (53)$$

and

$$\eta = 1 + 0.05k\,(1-R) \qquad \ldots (54)$$

Therefore, the steady-state rates of heat loss from the chosen reference houses for Groups I and II are respectively given by:

$$\dot{Q}_{ref,I}(j,k) = g_{1,I}(j,k)\,\dot{Q}_1 \qquad \ldots (55)$$

where

$$g_{1,I}(j,k) = \left(n/R + \frac{(0.05k)(K + 0.5)}{R}\ (U_{cr,j}/U_1) + 0.05k\ (U_{win}/U_1)\right) \quad \ldots (56)$$

and

$$\dot{Q}_{ref,II}(j,k) = g_{2,II}(j,k)\ \dot{Q}_1 \quad \ldots (57)$$

where

$$g_{2,II}(j,k) = \left(n\ \frac{(U_1 + U_2)}{R\ U_1} + \frac{(0.05k)(K + 0.5)}{R}(U_{cr,j}/U_1) + 0.05k\ (U_{win}/U_1)\right) \quad \ldots (58)$$

From equations (16), (19), (55) and (57), it can be proved that:

$$\left.\begin{array}{l} \dot{Q}_{n,I}(j,k) - \dot{Q}_{ref,I}(j,k) = g_{n,I}(j,k)\ \dot{Q}_1 \\ \text{and} \\ \dot{Q}_{n,II}(j,k) - \dot{Q}_{ref,II}(j,k) = g_{n,II}(j,k)\ \dot{Q}_1 \end{array}\right\} \quad \ldots (59)$$

where

$$\left.\begin{array}{l} g_{n,I}(j,k) = \left((n - 1)g(k) - \frac{1-R}{RU_1}\left\{U_1(1 + 0.05k) + 0.05k(k + 0.5)\ U_{cr,j}\right\}\right) \\ \text{and} \\ g_{n,II}(j,k) = \left((n-2)(g(k)-1) + \frac{F_n-U_2}{U_1} - \frac{1-R}{RU_1}\left((U_1+U_2)(1+0.5k)+0.05k(k+0.5)U_{cr,j}\right)\right) \end{array}\right\}$$

It can be deduced, using equations (16), (19) and (47) through to (60), and taking into consideration equation (12), that:

<u>For R = 1:-</u>

$$\left.\begin{aligned}
&U_{n,I}(j,k) - (1/n)U_{1,I}(j,k) = \\
&\left(\frac{(n-1)}{n}\quad g(k) + \left(\frac{h_{o,n}}{h_{o,1}}\right)\left(\frac{h_i + h_{o,1} + h_i h_{o,1} \sum_i d_i/\lambda_i}{h_i + h_{o,n} + h_i h_{o,n} \sum_i d_i/\lambda_i}\right)\right) U_1 \\
&U_{n,II}(j,k) - (2/n)U_{2,II}(j,k) = \\
&\left((1/n)g_n(k) + \left(\frac{h_{o,n}}{h_{o,1}}\right)\left(\frac{h_i + h_{o,1} + h_i h_{o,1} \sum_i (d_i/\lambda_i)_{n=1}}{h_i + h_{o,n} + h_i h_{o,n} \sum_i (d_i/\lambda_i)_{n>1}}\right)\right) U_1
\end{aligned}\right\} \quad \ldots (61)$$

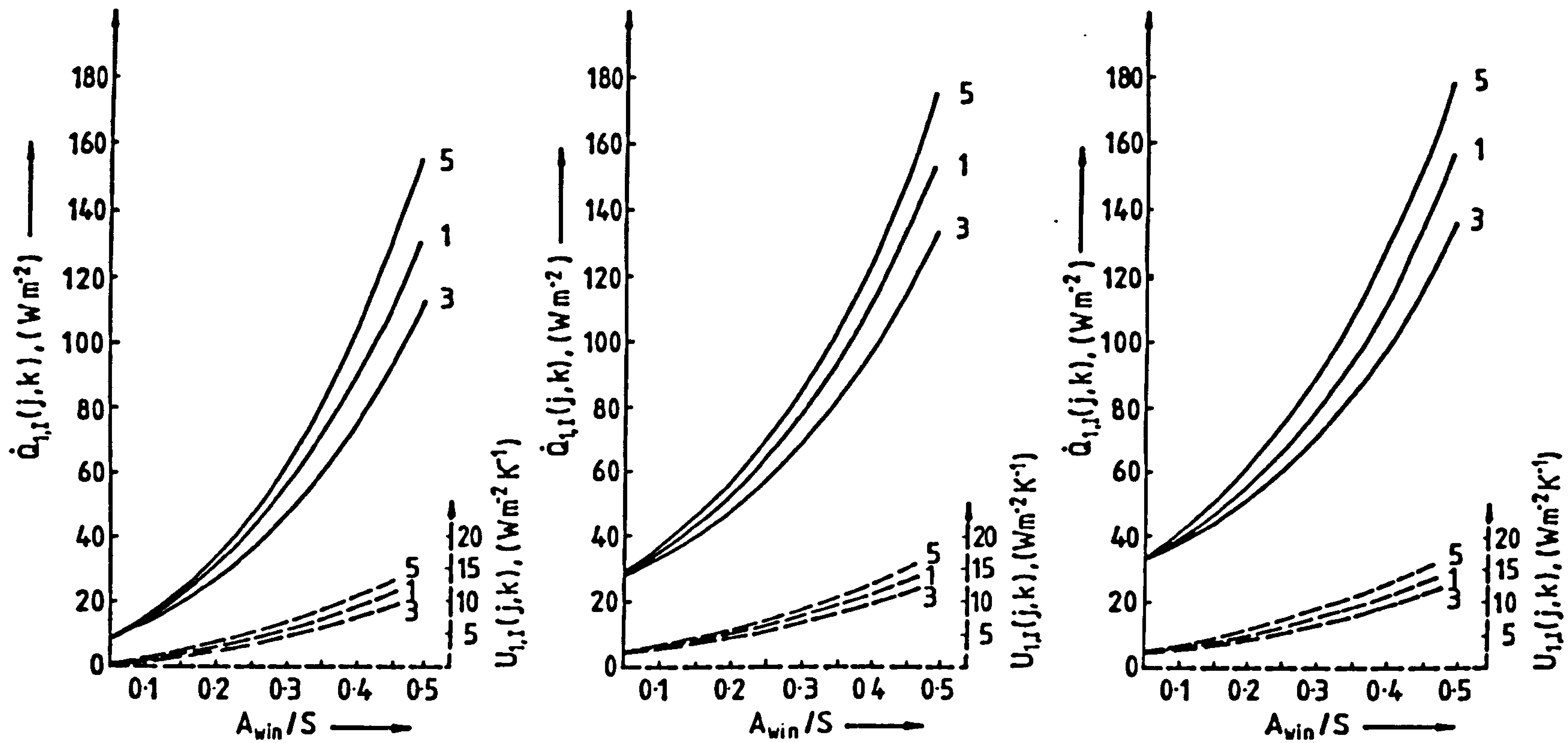
For R < 1:-

$$\left.\begin{aligned}
&U_{n,I}(j,k) - \frac{n}{nR}\ U_{1,I}(j,k) = \\
&\left((1/n)g_{n,I}(j,k) + \left(\frac{h_{o,n}}{h_{o,1}}\right)\left(\frac{h_i + h_{o,1} + h_i h_{o,1} \sum_i (d_i/\lambda_i)}{h_i + h_{o,n} + h_i h_{o,n} \sum_i (d_i/\lambda_i)}\right)\right) U_1 \\
&U_{n,II}(j,k) - \frac{2n}{nR}\ U_{2,II}(j,k) = \\
&\left((1/n)g_{n,II}(j,k) + \left(\frac{h_{o,n}}{h_{o,1}}\right)\left(\frac{h_i + h_{o,} + h_i h_{o,1} \sum_i (d_i/\lambda_i)_{n=1}}{h_i + h_{o,n} + h_i h_{o,n} \sum_i (d_i/\lambda_i)_{n>1}}\right)\right) U_1
\end{aligned}\right\} \ldots (62)$$

The predictions for (i) a single-storey mud house, (ii) a single-storey house with a concrete internal leaf and stone external cladding, and (iii) a single-storey concrete house, are illustrated in Figure 6a,b and c.

How to Use the Model

The thermal behaviours of buildings throughout a complete year can be predicted by means of computer based simulations. However, the use of such computer programs frequently requires a full year's record of hourly observations of weather conditions for each building's location. Thus, in order to evaluate the thermal response to an annual cycle of conditions




(a) SINGLE-STOREY HOUSE WITH TYPE 4 WALLS (AS IN FIG. 3).

(b) SINGLE-STOREY HOUSE, WALLS OF TYPE 7 (AS IN FIG. 3).

(c) SINGLE-STOREY HOUSE WITH TYPE 3 WALLS (AS IN FIG 3).

FIG. 6 PREDICTED STEADY-STATE HEAT LOSSES FOR SINGLE-STOREY HOUSES WITH DIFFERENT ROOF CONSTRUCTIONS; THE LATTER BEING INDICATED BY THEIR TYPE NUMBERS, AS DESIGNATED IN FIGURE 2.

the program must perform at least 8760 separate calculations. As a result such programs involve excessive computer times and are thus often too expensive to use. They are probably also inappropriate methods for designers in developing countries.

In an ideal design-process for a building, a thermal analysis would be performed in order to evaluate the thermal consequences of <u>each</u> major design option.

The architect may then select the most effective option for that building and intended occupancy pattern. To achieve this, the simplified approach described has been evolved. Using it and knowing the available choices in the house specification (such as the number of storeys, type and materials of the external walls, design and materials for the roof, and the ratio of glazed-to-wall areas), the designer can from the presented equations and graphs evaluate each option. The thermal performance of each house design is characterised by two factors, namely

i) the U-factor for the house and this can be deduced from equations (12), (61) and (62)

and

ii) the steady-state heat leak $\dot{Q}$, obtained via equations (16) and (19).

<u>Example</u>: To illustrate the application of the presented mathematical model we will consider a 3-storey mud house with the specifications given in Table 3.

| | |
|---|---|
| Roof type (see Fig. 2) | 3 |
| Inside wall plaster wall type (see Fig. 3) | 4 |
| $A_{win}/S$ | 0.25 |
| S(in $m^2$) | 100 |

<u>Table 3</u> Specifications for the walls and roof of the considered house.
Steps in the calculation:-

- From Fig. 3, $U_1 = 0.72\ W\ m^{-2}K^{-1}$

  Assume a fixed internal house temperature, $T_i$, of 22°C and use the seasonal average ambient temperature, i.e. 16°C in winter and 20°C in summer.

- From equation (11):-

  During the winter, $\dot{Q}_1 = U_1\ S\Delta T = (0.72)(100)(22 - 16) = 432$ W

  and during the summer, $\dot{Q}_1 = U_1\ S\Delta T \doteq (0.72)(100)(22 - 20) = 144$ W

- Evaluate the following parameters for $A_{win}/S = 0.25$:-

  From equation (18), $C_3(j,k) = 4.616$

  From equation (17), $M_3(j,k) = 7.616$

- Use equation (16) to evaluate $\dot{Q}_{n,I}(j,k)$

- Use equations (12) and (61) and Table 1 to evaluate $U_{n,I}(j,k)$

- Use equations (45) and (46) to determine the steady-state and transient-state rates of heat loss from the house.

The results are presented in Table 4.

TABLE 4

CONCLUSIONS FOR THE 3-STOREY HOUSE SPECIFIED IN TABLE 3

| Exterior wall material | | | U-factor ($Wm^{-2}K^{-1}$) | | Heat loss (GJ/day) from the house | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | steady-state | | transient-state | |
| First storey | Second storey | Third storey | roof | wall | winter | summer | winter | summer |
| Mud | Mud | Mud | 1.83 | 0.72 | 0.284 | 0.095 | 0.224 | 0.067 |

It must be emphasised that, despite contrary conventional practice, because of its low structural strength, it is not recommended that mud should be employed as the building material for multi-storey structures.

## Deductions

For houses built of similar exterior wall materials, the difference between the rate of heat loss from the n-storey house and that from the reference house is given by:-

$$\dot{Q}_{n,I}(j,k) - \dot{Q}_{ref,I}(j,k) = g_{n,I}(j,k)\,\dot{Q}_1 \qquad \dots (63)$$

According to equation (63), the smallest difference between $\dot{Q}_{n,I}(j,k)$ and $\dot{Q}_{ref,I}(j,k)$ occurs when $g_{n,I}(j,k) < 1$. Thus, to reduce the rate of heat loss relative to that of the reference house under similar circumstances, it is recommended that the wall/roof length ratio be such that:

$$R \leqslant \left(1 + F_{n,I}(j,k)\right)^{-1} \quad \text{for } n > 1 \qquad \dots (64)$$

where

$$F_{n,I}(j,k) = \left((n-1)g(k)\right) \Big/ \left\{1 + 0.05k\left(1 + (k + 0.5)(U_{cr,j}/U_1)\right)\right\} \qquad (65)$$

However, if the n-storey house is an exact duplicate of the chosen reference house, i.e. R = 1, this difference becomes an integral multiple of the rate of heat loss from the walls of the house of n-storeys, i.e.

$$\dot{Q}_{n,I}(j,k) - \dot{Q}_{1,I}(j,k) = (n - 1)\,g(k)\,\dot{Q}_1 \qquad \dots (66)$$

On the other hand, the difference between $\dot{Q}_{n,II}(j,k)$ and $\dot{Q}_{ref,II}(j,k)$ depends upon the number of storeys as well as upon the U-factors for the individual walls and roof, i.e.

$$\dot{Q}_{n,II}(j,k) - \dot{Q}_{ref,II}(j,k) = g_n(k)\,Q_1, \quad \text{for } n > 2 \text{ and } R = 1 \dots (67)$$

$$\dot{Q}_{n,II}(j,k) - \dot{Q}_{ref,II}(j,k) = g_{n,II}(j,k)\,\dot{Q}_1, \quad \text{for } n > 2 \text{ and } R < 1 \qquad \dots (68)$$

For each specified value of R, the smallest difference between $\dot{Q}_{n,II}(j,k)$ and $\dot{Q}_{ref,II}(j,k)$ occurs when $g_n(k) \leqslant 1$ or $g_{n,II}(j,k) \leqslant 1$.

Thus, to reduce the heat leaks through the material of an n-storey house, we recommend choosing the nth-storey material and the ratio of wall length respectively such that:-

$$\frac{U_{win}}{(U_1 - (F_n - U_2))} \leqslant \frac{1}{((n-2)(0.05k))}, \text{ for } n > 2 \text{ and } R = 1 \qquad \dots (69)$$

and

$$R \leqslant \left(F_{n,II}(j,k) + 1\right)^{-1}, \quad \text{for } n > 2 \text{ and } R < 1 \qquad \dots (70)$$

where

$$F_{n,II}(j,k) = \left(F_n - U_2 - U_1 + (n-2)(g(k)-1)U_1\right) \Big/ \left(U_1 + U_2 + 0.05k\left(U_1 + U_2 + (k+0.5)U_{cr,j}\right)\right) \qquad \dots (71)$$

The length ratio, R, of a wall of the reference house to that of the n-storey house, for which the difference between $\dot{Q}_{n,I}(j,k), \dot{Q}_{ref,I}(j,k)$ and $\dot{Q}_{n,II}(j,k), \dot{Q}_{ref,II}(j,k)$ are minimal can be calculated, using equations (64) and (65) for Group I houses and equations (70) and (71) for Group II houses, from the following expressions:

<u>For Group I houses</u>

$$R \leqslant \left(1 + \frac{(n-1)(U_1 + 0.05k\,U_{win})}{(1 + 0.05k)U_1 + 0.05k(k+0.5)U_{cr,j}}\right)^{-1} \qquad \dots (72)$$

<u>For Group II houses</u>

$$R \leqslant \left(1 + \frac{(n-2)\left(0.05k\,U_{win} + (F_n - U_1 - U_2)/(n-2)\right)}{(1 + 0.05k)(U_1 + U_2) + 0.05k(k+0.5)U_{cr,j}}\right)^{-1}$$

Using euqations 72 and 73, the dependence of the upper limits for the value of R on the glazed-to-solid wall area ratio, k, is illustrated for n = 4 in Figure 7, for the following particular external walls:-

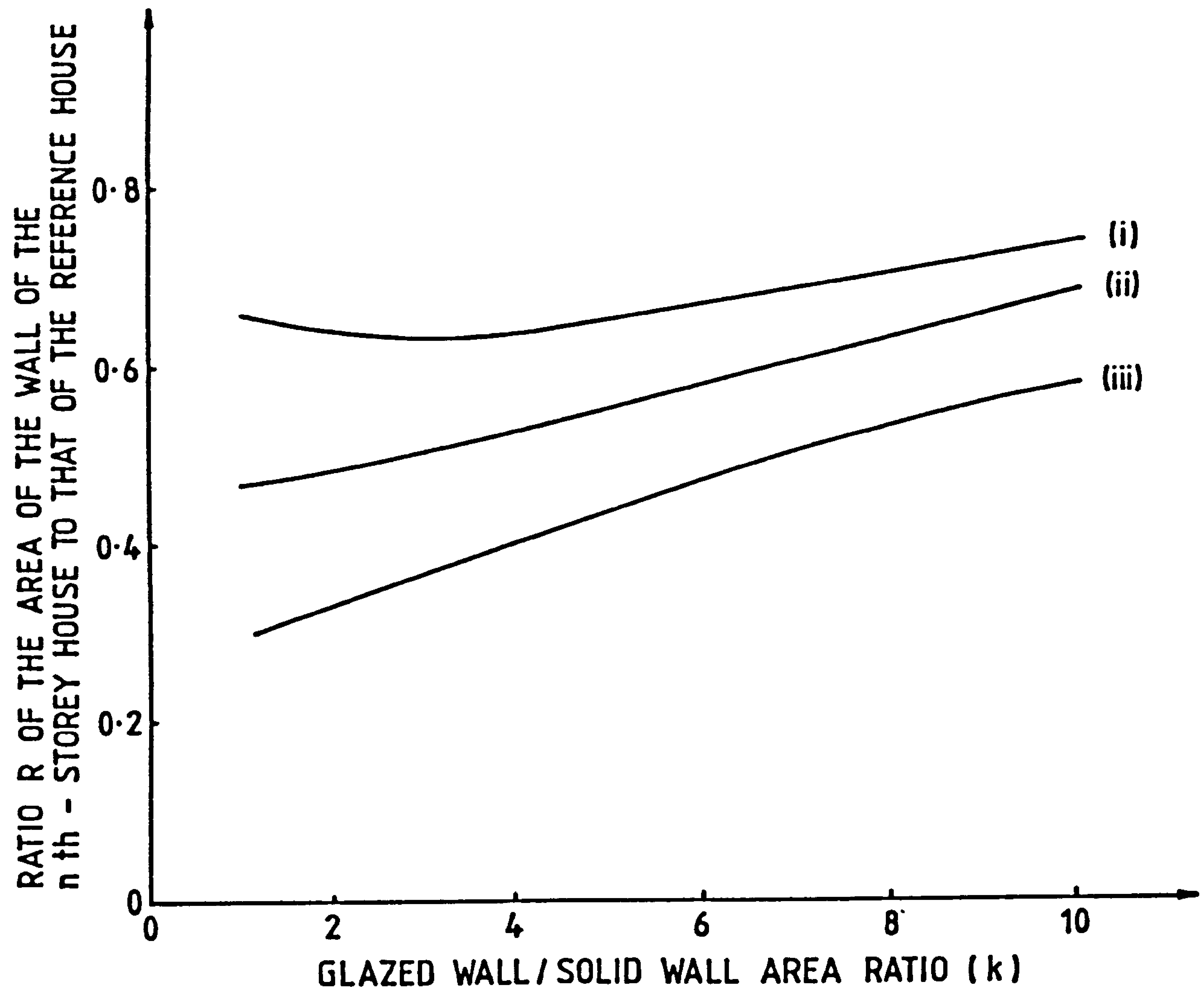



FIG 7. THE UPPER LIMITS OF WALL AREA RATIO, R, AS A FUNCTION OF THE GLAZED-TO-WALL AREA RATIO, k.

(i) stone (i.e. type 1 in Fig. 3) for the first storey and red brick (i.e. type 2 in Fig. 3) for all the higher storeys;

(ii) same as case (i) but the second, third and fourth storeys are built from concrete (i.e. type 3 in Fig. 3);

and(iii) stone (i.e. type 1 in Fig. 3) for all four storeys.

The choice of these particular arrangements is justified by their popularity in the Yemen, where case (i) is most commonly used followed, for economic reasons, by cases (ii) and (iii). In all cases, the upper limits for R plotted in Figure 7 are for buildings with the same roof type 1 construction (see Fig. 2) which has a U-value of 2.26 W $m^{-2}K^{-1}$. It was also assumed that all windows are single glazed and here a U-value of 4.3 W $m^{-2}K^{-1}$ is used.

The difference between the rate of heat loss from a Group I house and that from a Group II house illustrates the effect of the type of external wall constructional material on the steady-state rate of heat loss. From equations (16) and (19) it can be deduced that:-

$$\dot{Q}_{n,II}(j,k) - \dot{Q}_{n,I}(j,k) = \left(\frac{n}{U_1(n-1)} - 1\right)(n-1)\,\dot{Q}_1 \qquad \ldots (74)$$

This equation implies, for $n > 2$, that

$$\text{if } F_n \Big/ \left\{U_1(n-1)\right\} < 1, \text{ then } \dot{Q}_{n,II}(j,k) < \dot{Q}_{n,I}(j,k) ;$$

$$\text{if } F_n \Big/ \left\{U_1(n-1)\right\} > 1, \text{ then } \dot{Q}_{n,II}(j,k) > \dot{Q}_{n,I}(j,k) ;$$

$$\text{or} \quad \text{if } F_n \Big/ \left\{U_1(n-1)\right\} = 1, \text{ then } \dot{Q}_{n,II}(j,k) = \dot{Q}_{n,I}(j,k)$$

The ratio $\{F_n/U_1(n-1)\}$ is plotted for $n = 2,3$ and 4 in Figure 8. According to this figure, the condition $\dot{Q}_{n,II}(j,k) < \dot{Q}_{n,I}(j,k)$ is satisfied when a multi-storey house is built of the vernacular arrangement of walls constructed from stone and red brick, or stone and mud. Thus if the same design of multi-storey house is to be built wholly in either stone, red brick or mud rather than in a storey-by-storey sequence of these materials i.e. stone for the first storey and red brick or mud for all the successive higher storeys, the steady state rate of heat loss from the house will be greater.

On the other hand, the Yemeni vernacular arrangements of stone for the first storey and concrete or reinforced concrete for all the higher storeys (see Fig. 8), satisfy the condition $\dot{Q}_{n,II}(j,k) > \dot{Q}_{n,I}(j,k)$. The steady-state rate of heat loss from a multi-storey house built wholly in stone, concrete or reinforced concrete is less compared with that of a multi-storey house with stone for the first storey and concrete or reinforced concrete for all the higher storeys.

The third condition i.e. when $\dot{Q}_{n,II}(j,k) = \dot{Q}_{n,II}(j,k)$, does not occur for the storey-by-storey sequences of wall types used at present in the Yemen (see Fig. 8).

The application of the model was extended to buildings with selected particular storey-by-storey sequences of wall types which are <u>not</u> presently constructed in the Yemen. Some of these different arrangements result from reversing the order of some of the conventionally-employed sequences. The deductions can be seen as dotted lines in Figure 8. These arrangements satisfy the same condition, i.e. $\dot{Q}_{n,II}(j,k) < \dot{Q}_{n,I}(j,k)$, as those of stone and red brick or stone and mud.

## CONCLUSIONS

A simple mathematical model for predicting the steady-state total rate of heat loss from a building has been developed. On comparing the steady-state predictions obtained by using it with those from a more realistic, but more complicated, transient model, it was found that the steady-state equations can be used to deduce the daily average rate of heat loss from a Yemeni house by employing reduction factor of 0.71 in the summer and 0.79 in winter. By substituting the likely inaccuracies in the input data to the presented mathematical model, it is deduced that the predicted rates of heat leak will not be error by more than 10%. The advantage of the steady-state formulation to designers is that it uses readily-available data and only requires straight-forward calculations

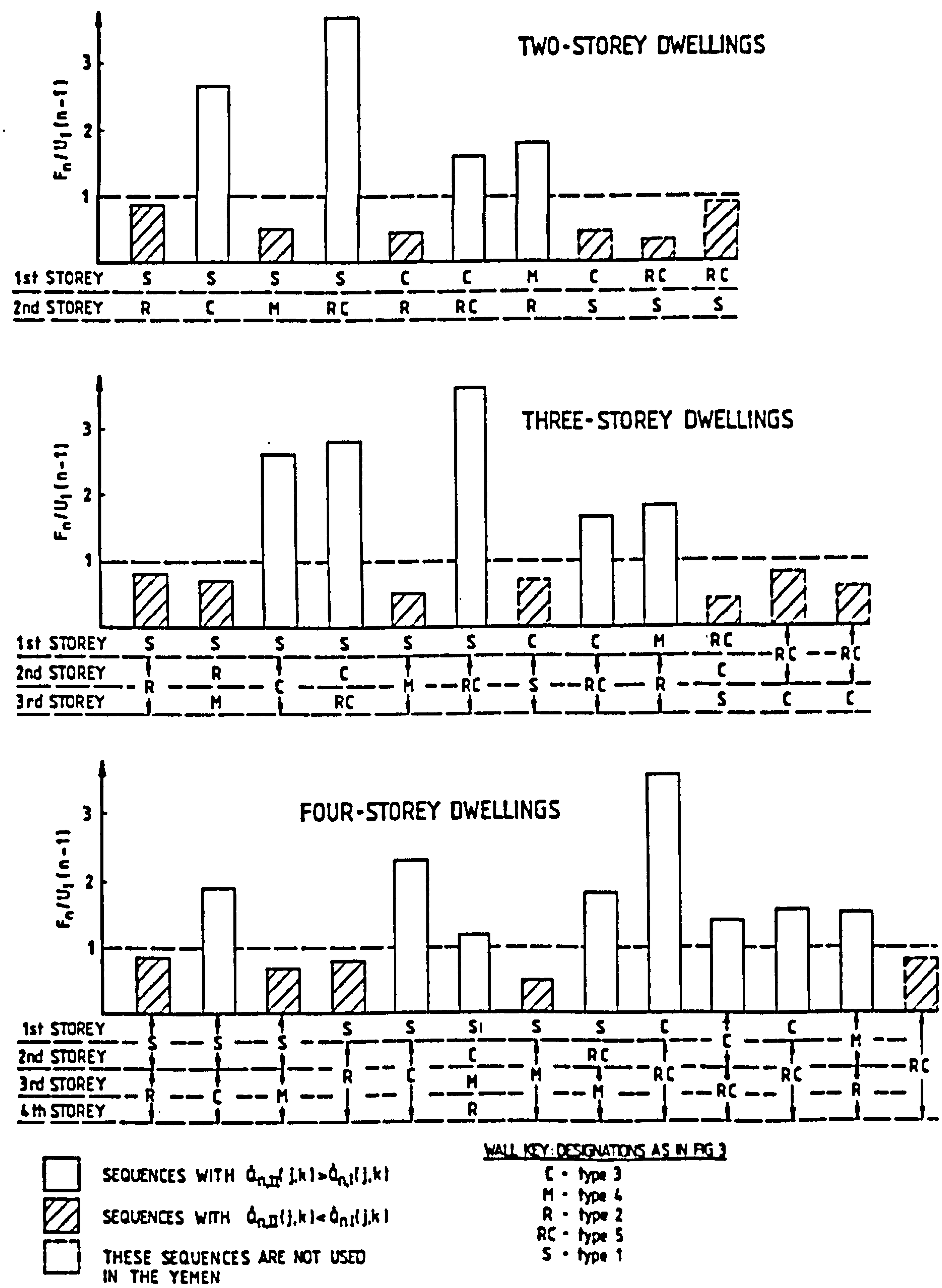



FIG. 8. INDICATIONS OF THE RATES OF HEAT LOSS FROM DWELLINGS IN THE YEMEN ARAB REPUBLIC : EFFECTS OF DIFFERENT VERTICAL LAYERS OF MATERIALS IN THE WALLS.

and relatively short computational times. It is compatible with the level of the generally-available computational technology in the Yemen and thus should find ready application there.

Finally it should be noted that the modern wall types (namely 3 and 5 to 8 walls as shown in Figure 3) give larger steady-state rates of heat loss when compared with the traditional vernacular wall types (namely 1,2 and 4 in Fig. 3).

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# CHAPTER 4

## SOLAR-ENERGY HARNESSING PERFORMANCES OF DIRECT-GAIN AND TROMBE WALLS UNDER YEMENI WEATHER CONDITIONS

# GLOSSARY

**Direct-gain house:** In the northern hemisphere, essentially a house whose south-facing wall is of single-glazed glass.

**House heating load:** The amount of energy required for space-heating.

**Un-vented Trombe Wall:** A south-facing thermal storage wall with its glazed, blackened surface facing towards the ambient environment. In this analysis, the area of the heat storage wall facing south equals that of its glazing.

**Utilizability function:** That fraction of the incident solar radiation penetrating into the house, which exceeds the house's heating load.

## NOMENCLATURE

| | | |
|---|---|---|
| $a$ | Constant, as defined by equation (7a) | |
| $A_C$ | Area of the south-facing passive heating element | $m^2$ |
| $A_F$ | Floor area of the considered house | $m^2$ |
| $A_S$ | Area of the direct-gain storage floor or the Trombe heat-storage wall | $m^2$ |
| $A_{win,i}$ | Total window area in the ith direction, where i=1, 2 or 3 indicates east, west, or north respectively | $m^2$ |
| $b$ | Constant, as defined by equation (7b) | |
| $B$ | Thermal efficiency function of the considered house, as defined by equation (63) | $W\ m^{-2}\ K^{-1}$ |
| $c$ | Constant, as defined by equation (7c) | |
| $C_a$ | Specific heat of air (= 1200 $J\ kg^{-}\ K^{-}$ ) | |
| $C_s$ | Specific heat of the direct-gain storage floor or the Trombe heat-storage wall - see Table 1 | $J\ kg^{-1}\ K^{-1}$ |
| $d$ | Thickness of the storage element - see Table 1 | m |
| $f(t_d),\bar{F}$ | Hourly and daily average values of the direct-solar gain factor respectively, as defined by equations (18) and (24) | |
| $g(t_d),\bar{g}$ | Dimensionless parameters, as defined respectively by equations (11) and (25) | |
| $g_{sd},g_{sw}$ | Dimensionless storage parameters, as defined respectively for direct solar-gain and Trombe wall systems by equations (55) and (56) | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\bar{H}_T$ | Monthly average of the daily amounts of solar radiation falling per unit area on the south-facing vertical wall - see Fig. 1. | MJ $m^{-2}day^{-1}$ |
| $\bar{H}_{T,i}$ | Monthly average of the daily amounts of solar radiation falling per unit area on the vertical walls facing east (i=1), west (i=2), and north (i=3) | MJ $m^{-2}day^{-1}$ |
| $\bar{H}_\tau$ | Monthly average of the daily amounts of solar radiation transmitted to the living space, as defined by equation (62) | MJ $m^{-2}day^{-1}$ |
| i | Integer, which takes the values 1, 2 or 3 so designating respectively the easterly, westerly,or northerly directions | |
| $I_c$ | Critical radiation intensity, as defined by equation (2) | W $m^{-2}$ |
| $I_{t,\theta}$ | Hourly rate of radiation falling per unit area on a surface inclined at an angle θ to the horizontal: average values calculated over several days | W $m^{-2}$ |
| $\bar{I}_{t,\theta}$ | Hourly average solar radiation falling per unit area on a surface inclined at an angle θ to the horizontal | W $m^{-2}$ |
| k | Thermal conductivity of the storage floor or wall - see Table 1 | W $m^{-1}K^{-1}$ |
| $\bar{K}_T$ | Monthly average clearness index for the ambient environmental atmosphere - see reference (6) | |
| m | Mass per unit area of the storage element | Kg $m^{-2}$ |
| $(m\ C)_{sd}$, $(m\ C)_{sw}$ | Heat capacities respectively of the direct-gain storage floor and the Trombe heat-storage wall | J $m^{-2}K^{-1}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $n_d, n_n$ | Day-time and night-time durations see Fig. 2. | sec |
| N | Number of days per calendar month | |
| p | Dimensionless parameter, as defined by equation (64) | |
| $\dot{q}_{cs}(t_d), \dot{q}_{cs}(t_n)$ | Transient rates of heat being conducted from the storage element to the living space, as defined respectively during the day or night by equations (14) and (15) | W |
| $\dot{q}_{int}(t_d), \dot{q}_{int}(t_n)$ | Day-time and night-time transient rates of heat contributions to the internal energy sources | W |
| $\dot{q}_{t,i}(t_d)$ | Rate of solar radiation falling on the house's vertical wall facing in the ith direction | W $m^{-2}$ |
| $\dot{q}_{Lost}(t_d), \dot{q}_{Lost}(t_n)$ | Day and night-time transient rates of heat being lost from the considered passively heated house to the ambient environment, as defined respectively by equations (12) and (13) | W |
| $\dot{q}_{Lw}(t_d), \dot{q}_{Lw}(t_n)$ | Day and night-time transient rates of heat being lost from the heat store wall to the ambient environment, as defined respectively by equations (32) and (33) | W |
| $\dot{q}_{solar}(t_d)$ | Transient rate of solar energy transmitted through the glazed elements of the considered direct-gain house, as defined by equation (10) | W |
| $\bar{Q}_{aux}$ | Monthly average of the daily amounts of auxiliary energy required by the considered passively-heated house, as defined by equation (57) | MJ $day^{-1}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\bar{Q}_{dd}$, $\bar{Q}_{dw}$ | Monthly average of the daily amounts of heat transferred to the room air during the day-time as defined respectively for direct-gain and Trombe wall passive-heating systems by equations (37) and (39) | MJ $day^{-1}$ |
| $\bar{Q}_{int}$ | Monthly average of the daily amounts of heat contributed from the internal energy resources, as defined by equation (17) | MJ $day^{-1}$ |
| $\bar{Q}_{Load}$ | Monthly average of the daily loads of the considered passively-heated house | MJ $day^{-1}$ |
| $\dot{Q}_{Lost}$ | Steady-state rate of heat lost from the considered house to the ambient environment, as defined by equation (23) | W |
| $\bar{Q}_{nd}$, $\bar{Q}_{nw}$ | Monthly average of the daily amounts of heat transferred to the room air during night-time, as defined for direct-gain and Trombe wall systems by equations (38) and (40) respectively | MJ $day^{-1}$ |
| $\bar{Q}_{solar}$ | Monthly average of the daily amounts of solar radiation transmitted through the glazed elements of the considered house, as defined by equation (22) | MJ $day^{-1}$ |
| $\bar{Q}_R$ | Monthly average of the daily amounts of residual energy, as defined for direct-gain and Trombe wall systems by equations (45) and (46) respectively | MJ $day^{-1}$ |
| $\bar{Q}_{udd}$, $\bar{Q}_{udw}$ | Monthly average of the daily amounts of day-time useful solar gains, as defined for direct-gain and Trombe wall systems by equations (47) and (49) respectively | MJ $day^{-1}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\bar{Q}_{und}, \bar{Q}_{unw}$ | Monthly average of the daily amounts of night-time useful solar gains, as defined for direct-gain and Trombe wall systems by equations (48) and (50) respectively | MJ day$^{-1}$ |
| $\bar{R}$ | Average, over a 24-hour continuous period of the heat-loss reduction factor | |
| $R_b$ | Ratio of the daily direct solar radiation falling on a surface, at inclination $\theta$, to that on a horizontal surface | |
| $R_n$ | Ratio of the total solar radiation falling on a surface, at inclination $\theta$, to that on a horizontal surface both at noon at the same location | |
| $\bar{R}_t$ | Monthly average ratio of the global solar radiation falling on a surface inclined at $\theta$ to the horizontal to that falling on a horizontal surface at that same location | |
| $t_d, t_n$ | Elapsed time for day and night respectively | sec |
| $T_a(t_d), T_a(t_n)$ | Mean day-time and night-time outside ambient environment's air temperature respectively, i.e. evaluated over the periods $t_d$ and $t_n$ respectively | K |
| $T_c$ | Fixed thermostat set temperature | K |
| $T_i(t_d), T_i(t_n)$ | Mean day-time and night-time indoor air temperatures evaluated over the periods $t_d$ and $t_n$ respectively | K |
| $T_s(t_d), T_s(t_n)$ | Mean day-time and night-time storage element temperatures, evaluated respectively over the periods $t_d$ and $t_n$ - see equations (8) and (9) | K |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $T_{sd}(t_d), T_{sd}(t_n)$ | Mean day-time and night-time storage temperatures evaluated for the direct-gain house over the periods $t_d$ and $t_n$ respectively - see equations (27) and (28) | K |
| $T_{sd}(0), T_{sd}(n_d)$ | Storage temperatures for the direct-gain house evaluated respectively at $t_d$ equal to zero and $n_d$ | K |
| $T_{sw}(t_d), T_{sw}(t_n)$ | Mean day and night times storage temperatures for a Trombe wall system evaluated respectively over the periods $t_d$ and $t_n$ by equations (34) and (35) | K |
| $T_{sw}(0), T_{sw}(n_d)$ | Storage temperatures of a Trombe wall system evaluated respectively at $t_d$=0 and $n_d$ respectively | K |
| $\bar{T}_a$ | Monthly average outside ambient air temperature - see Fig. 2 | K |
| $\bar{T}_i$ | Actual monthly average indoor temperature as defined by equation (58) | K |
| $\bar{T}_r$ | Monthly average reference indoor temperature, as defined by equation (26) | K |
| $U_{eqv}$ | An equivalent heat-transfer coefficient for the considered house, as defined by equation (4) | $W\ m^{-2}K^{-1}$ |
| $(UA)_h$ | Overall thermal conductance of the considered house, as defined by equation (3) | $W\ K^{-1}$ |
| $U_i$ | Heat-transfer coefficient for the inner surface of the storage element relative to the air in the room - see Table 1 | $W\ m^{-2}K^{-1}$ |
| $\bar{U}_L$ | Average heat-transfer coefficient from the outer surface of the heat store through the south-facing glazing to the ambient environment - See Table 1. | $W\ m^{-2}K^{-1}$ |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $U_s$ | Heat-transfer coefficient from the store to the living space, as defined by equation (16) | $W\ m^{-2}K^{-1}$ |
| $U_{sd}, U_{sw}$ | Heat-transfer coefficients from the storage floor of the direct-gain system and the heat-storage wall of the Trombe wall system respectively to the air in the room | $W\ m^{-2}K^{-1}$ |
| $\dot{V}$ | Rate of ventilation (in this analysis taken as 1 $m^3\ hr^{-1}$) | $m^3\ hr^{-1}$ |
| $X_c$ | Ratio of the critical radiation intensity to the average hourly radiation intensity falling on the inclined collector surface | |
| $\bar{X}_c$ | Monthly-average critical radiation ratio, as defined by equation (5) | |
| $Y, Y_1$ | Dimensionless constants, as defined respectively by equations (66) and (71) | |
| $\Delta t$ | Duration of a day (i.e. $\Delta t$=86400 sec) | sec |
| $\Delta T$ | Temperature difference between the thermostat set temperature and the monthly average outside ambient air temperature | $^oC$ |
| $\phi$ | Utilizability function - see the glossary | |
| $\bar{\phi}$ | Monthly average daily utilizability function, as defined by equation (1) | |
| $\eta_{rec,d}, \eta_{rec,w}$ | Ambient-energy recuperation factors, as defined for the direct-gain and Trombe wall systems respectively, by equations (53) and (54) | |

## NOMENCLATURE (cont)

| | | |
|---|---|---|
| $\rho_a$ | Density of air: it is assumed for present analysis that $\rho_a = 1$ kg m$^{-3}$ | kg m$^{-3}$ |
| $\rho_s$ | Density of the storage elements - see Table 1 | kg m$^{-3}$ |
| $(\bar{\tau}\alpha)$ | Monthly average glass transmittance-storage element absorptance product - see Table 1 | |
| $\tau_{sd}, \tau_{sw}$ | Thermal time constants, as defined for the direct-gain and Trombe-wall systems by equations (29) and (36) respectively | sec |

# CHAPTER FOUR

## SOLAR-ENERGY HARNESSING PERFORMANCES OF DIRECT-GAIN AND TROMBE WALLS UNDER YEMENI WEATHER CONDITIONS

### INTRODUCTION

Space heating and cooling requires approximately 40% of the total house energy loads in typical Yemeni residential buildings {1}. Thus accurate means for predicting such energy demands are desirable when considering rival designs of space heating and cooling systems. It is generally accepted that a building can be designed to be more energy effective if its thermal insulation is increased; window size optimised, air leakage and lighting levels decreased; shading devices properly installed; heating and cooling systems better designed, installed and maintained and the building structure's storage capacity more fully utilized. However these energy-saving features must be considered with reference to numerous constraints, such as (i) the added costs for materials, construction and maintenance which would be increased, (ii) conformation with the local building practices and life styles of the occupants, and (iii) availability of suitable heating and cooling equipment at an economic cost.

One way to deduce the required optimal heating and cooling systems (i.e. those leading to minimum total energy consumption), is to study the buildings thermal performance by using mathematical simulations which describe the buildings thermal behaviour. To this end, simplified methods {2-11} have been developed. The initial aim of such research was to estimate or maximise energy savings achievable. Now the aim is shifting more towards the improvement of comfort and convenience for the occupants of the house.

The object of this study is to balance the heat losses with heat gains both being described by functions of the climate and building design parameters. The advantage of this method compared with the solar-load ratio method {3} is that the latter is limited in terms of design variables which are considered. For example, the latter does not allow the designer to investigate the effects of varying the solar absorptance, the building's heat storage capacity as well as high and low thermostat set temperatures. Although the correlations of the "un-utilizability" method {4,5} are useful in that they provide designers with a value for the solar heating fraction resulting from adopting a particular design, they do not provide information concerning the cooling auxiliary requirements and the variations of the house temperature with respect to time. However, these are often of more importance, particularly in hot climates, than the solar contribution to the building's heating requirements. Thus the advantage of the present design method, compared with the "un-utilizability" method, lies in its ability to provide an estimate, in addition to the auxiliary requirements for heating, those for cooling as well as the variation of the temperature within the house with respect to time. In other words, the present method is appropriate for positive as well as negative differences between the thermostat set temperature and the variable ambient environment's air temperature.

There is an analogy between the physical meanings of the dimensionless parameters introduced in this analysis and the corresponding ones of the utilizability method {4-6}. Thus in Section 1 of this paper, the utilizability concept, and its applications to direct-gain and un-vented Trombe wall systems are reviewed. The development of the ambient-energy recuperation factor along with the fundamental physical considerations upon which the formalism was based are presented in Section 2. In the third section we link the physical meanings of the dimensionless parameters used in this analysis to those of the utilizability method. In the final section of the paper, the formalism is applied to direct-gain and un-vented Trombe wall systems and the results compared, as far as auxiliary heating requirements are concerned, with those of Monsen et al {4,5}. In the same section the annual thermal performances of direct-gain and un-vented Trombe walls systems are compared.

SECTION 1: The Utilizability Method {4-11}

This is a valuable technique for calculating the long-term thermal performances of solar systems designed for heating applications. The concept ot utilizability was developed originally from the Hottel-Whiller-Bliss equation {12-15}, which relates the rate of the useful-energy collection to the design parameters and operating conditions of a flat-plate solar-energy collector experiencing a constant fluid-flow rate. The utilizability, $\phi$, of insolation is defined as the fraction of the average hourly radiation, $I_{t,\theta}$, which is above a specified critical radiation level $I_c$. The critical radiation ratio, $X_c$, is defined as the ratio of the critical radiation intensity $I_c$ (the solar radiation intensity at which the solar input equals the house load) to the average hourly radiation intensity, $\bar{I}_{t,\theta}$, falling on the inclined collector surface. The $\phi$-curves, i.e. the plot of $\phi$ as a function of $X_c$, are independent of the hour but dependent on the month, location and orientation. Liu and Jordan {12,16} generalised Whillier's $\phi$-curve method by introducing the monthly average clearness index, $\bar{K}_T$, i.e. the ratio of the monthly average of the daily amounts of radiation falling on a horizontal surface to the extra-terrestrial radiation falling on the same surface. They showed that, over a long period such as a year, the distribution of daily total radiation corresponding to a given value of $\bar{K}_T$ is unique, and independent of location or time of the year. As a result they constructed the generalised $\phi$-curves for daily clearness indices ranging from 0.3 to 0.7: these curves were independent of the month or the location. They also incorporated the effect of inclination on the $\phi$-curves for surfaces facing south and constructed $\phi$-curves for a range of values of $R_b$ (the ratio of daily direct radiation on a tilted surface to that on a horizontal surface at the same location). These curves are good for calculations undertaken with input data corresponding to ambient-conditions at one-hour intervals. This means 3 to 6 such calculations each day of a month must be performed in order to obtain the total useful output energy for that month. This led Klein {6} to develop the concept of the monthly average of the daily utilizability function, $\bar{\phi}$. This function is defined as the sum for a month, over all hours, of the average hourly radiation intensities, which are above a critical radiation level, falling on an inclined surface divided by the average value over a month of the radiation intensity, $\bar{H}_T$. In equation form, the average over a month of the daily utilizability $\bar{\phi}$, is given by:

$$\bar{\phi} = \sum_{hour} \frac{(\bar{I}_{t,\theta} - I_c)}{\bar{N}\ H_T} \qquad \ldots (1)$$

where $I_C$ is the critical radiation level, i.e. the level of solar radiation at which the solar input equals the house load. It has been defined {4,5} for passive solar-energy applications purposes by:

$$I_C = (UA)_h \left( (\bar{T}_r - \bar{T}_a) / \ (\bar{\tau\alpha})\ A_C \right) \qquad \ldots (2)$$

where $(UA)_h$ is the overall thermal conductance of the outer fabric of the house, $\bar{T}_r$ is the monthly average reference indoor temperature, which equals the thermostat set temperature minus the increase in the internal temperature caused by the internal gains; $\bar{T}_a$ is the monthly average of the daily outdoor ambient air temperature - see Fig. 1; $(\bar{\tau\alpha})$ is the monthly average product of the transmittance of the glass and absorptance of the storage element's outer facing surface - see Table 1; and $A_C$ is the effective area of the vertical south-facing passive collector. The overall thermal conductance of the house is defined here as the sum of the heat losses via the fabric, ground and ventilation, i.e.

$$(UA)_h = U_{eqv}\ A_F \qquad \ldots (3)$$

where $A_F$ is the floor area of the considered house and $U_{eqv}$ is an "equivalent" heat-transfer coefficient defined in terms of the solid outer walls, roof, ground, ventilation and glazing heat-transfer coefficients by

$$U_{eqv} = (1/A_F) \left[ (UA)_{\substack{\text{south-}\\\text{facing}\\\text{collector}}} + (UA)_{\substack{\text{solid}\\\text{walls}}} + (UA)_{windows} + (UA)_{roof} + (UA)_{ground} + \rho_a C_a \dot{V} \right] \qquad \ldots (4)$$

where $\dot{V}$ is the rate of ventilation in cubic metres per hour and $\rho_a C_a = 0.34$ W hr/m³°C for air.

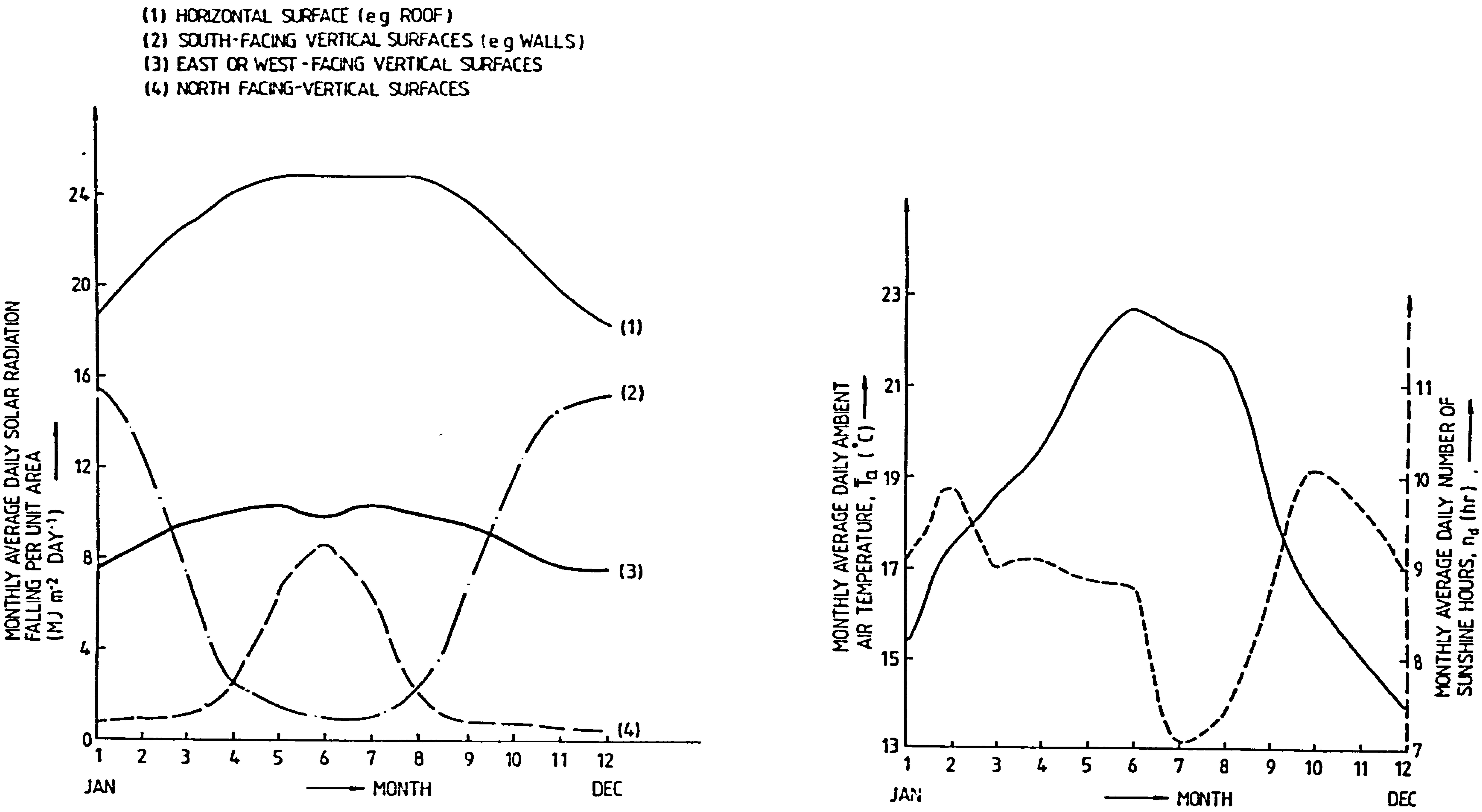



FIG. 1 MONTHLY AVERAGE METEOROLOGICAL DATA FOR THE CONSIDERED LOCATION.

TABLE 1: Values of the System Parameters Used in the Present Analysis

| Parameter | | Range | |
|---|---|---|---|
| Overall house thermal conductance | $,(UA)_h$ | 158 to 1400 | W/°C |
| House floor area | $,A_F$ | 132 to 200 | $m^2$ |
| Area of south-facing glazing | $,A_c$ | 5 to 50 | $m^2$ |
| Product of the density and specific heat for storage element | $,\rho_s C_s$ | 1.39 to 2.39 | $MJ/m^3 {}^\circ C$ |
| Thickness of the storage wall or floor | $,d$ | 0.05 to 0.4 | m |
| Thermal conductivity of the storage wall or floor | $,k$ | 0.465 to 1.745 | W/m C |
| Heat transfer coefficients | $,\bar{U}_L$ and $U_i$ | 3.7 and 8.3 | $W/m^2 {}^\circ C$ |
| Heat transfer coefficient of the glazed elements | $,U_g$ | 4.3 | $W/m^2 {}^\circ C$ |
| Heat capacity of the storage elements | $,((m\, C_s)/A_s)$ | 120 to 506 | $kJ/m^2 {}^\circ C$ |
| Thermostat set temperature | $,T_C$ | 18 to 27 | °C |
| Monthly average product of the glass transmittance and the absorptance of the storage elements | $,(\bar{\tau\alpha})$ | 0.6 to 0.85 | |

Correlations have been developed {6} for $\bar{\phi}$ as a function of $\bar{K}_T$ and two dimensionless variables namely a geometric factor, $\bar{R}_t/R_n$, and the monthly average critical radiation ratio $\bar{X}_c$. The geometric factor is the ratio of $\bar{R}_t$, the monthly ratio of the global radiation falling on the inclined surface considered to that falling on a horizontal surface, to $R_n$, the ratio of the total solar radiation falling on the inclined surface to that falling on the horizontal one both evaluated at solar noon for an average day of a month. The monthly average critical radiation ratio, $\bar{X}_c$, is the critical radiation intensity, $I_c$, divided by the total radiation intensity for that day of the month in which the total daily radiation is the same as the monthly average. In equation form, $\bar{X}_c$ is given by {6}:

$$\bar{X}_c = \left( I_c/(r_{tn}\ R_n\ \bar{K}_T\ \bar{H}_o) \right) \qquad \ldots (5)$$

where $r_{tn}$ is the ratio of the radiation at noon to the daily total radiation. $\bar{\phi}$-curves can be represented {6} by

$$\bar{\phi} = \exp\left(\left(a + b(R_n/\bar{R}_t)\right)\left(\bar{X}_c + c(\bar{X}_c)^2\right)\right) \qquad \ldots (6)$$

where a, b and c are constant expressed in terms of $\bar{K}_T$ as follows {17}:

$$a = 2.943 - 9.271\ \bar{K}_T + 4.031(\bar{K}_T)^2 \qquad \ldots (7a)$$

$$b = -\ 4.345 + 8.853\ \bar{K}_T - 3.602(\bar{K}_T)^2 \qquad \ldots (7b)$$

and

$$c = -\ 0.170 - 0.306\ \bar{K}_T + 2.936(\bar{K}_T)^2 \qquad \ldots (7c)$$

Theilacker {18} proposed simplifications to Klein's correlations, which improve the overall accuracy. Collares-Pereira and Rabl {8} have developed monthly average daily utilizability correlations for five collector types. However they defined the monthly average value of the daily utilizability as the fraction of the radiation incident on the collector surface while it is operating. In recent years, the utilizability concept has been used for evaluating the thermal performances of a wide range of solar-energy applications, from active solar collector systems, to photo-voltatic system designs, and to passively heated direct-gain and Trombe walls systems. The interpretation of the critical radiation level depends on the type of solar-energy application. For flat-plate and concentrating collectors, the radiation below the critical radiation level represents the absorbed radiation that is necessary to overcome the collector losses. The radiation above the critical level is then the "utilizable" portion of the absorbed radiation. On the other hand, for a passively-heated direct-gain house, the critical radiation level represents the building losses. The transmitted solar radiation below that level is used to warm the building, while the solar radiation above it is in excess of the load and must be removed by ventilation, cooling or drawing a shade, or stored for later use.

In all these applications the utilizability concept requires that the critical radiation level be constant over the period considered. This represents a limitation on the method when applied to solar-energy system performance calculations. The actual critical radiation level in most solar-energy systems, particularly those with a storage system, varies from hour-to-hour. The yearly utilizability correlations of Rabl {8} and Gordon and Zarmi {10,11} require the critical radiation level to be invariant over the whole year. Daily correlations require the critical radiation level to be constant for every hour in the month, but it may vary from one month to another.

Similarly, the hourly correlations require the critical radiation level to be a constant for each hourly period but it may differ from that for other hourly periods as well as for each month. These requirements limit the application of the utilizability method to those calculations which involve upper and lower bound limits on the system's performance.

## SECTION TWO: Mathematical Model

Consider a building having either a direct-gain or un-vented Trombe wall passive heating system as shown in Figures (2a) and (2b) respectively. The house in both cases is assumed to have the same design details with respect to the areas of the differently oriented walls and windows, floors and roof. For the un-vented Trombe wall system, Fig. 2b, the area of the south-facing heat-storage wall is taken to be equal to the area of its glazing. It is also assumed that the house, in both cases, has a back-up system which ensures that the air temperature within the house never falls below that fixed by the thermostat-set temperature, $T_C$. In those situations when the internal air temperature exceeds $T_C$, it is assumed that the excess energy can be dumped by ventilation or stored in the building structure for use later.

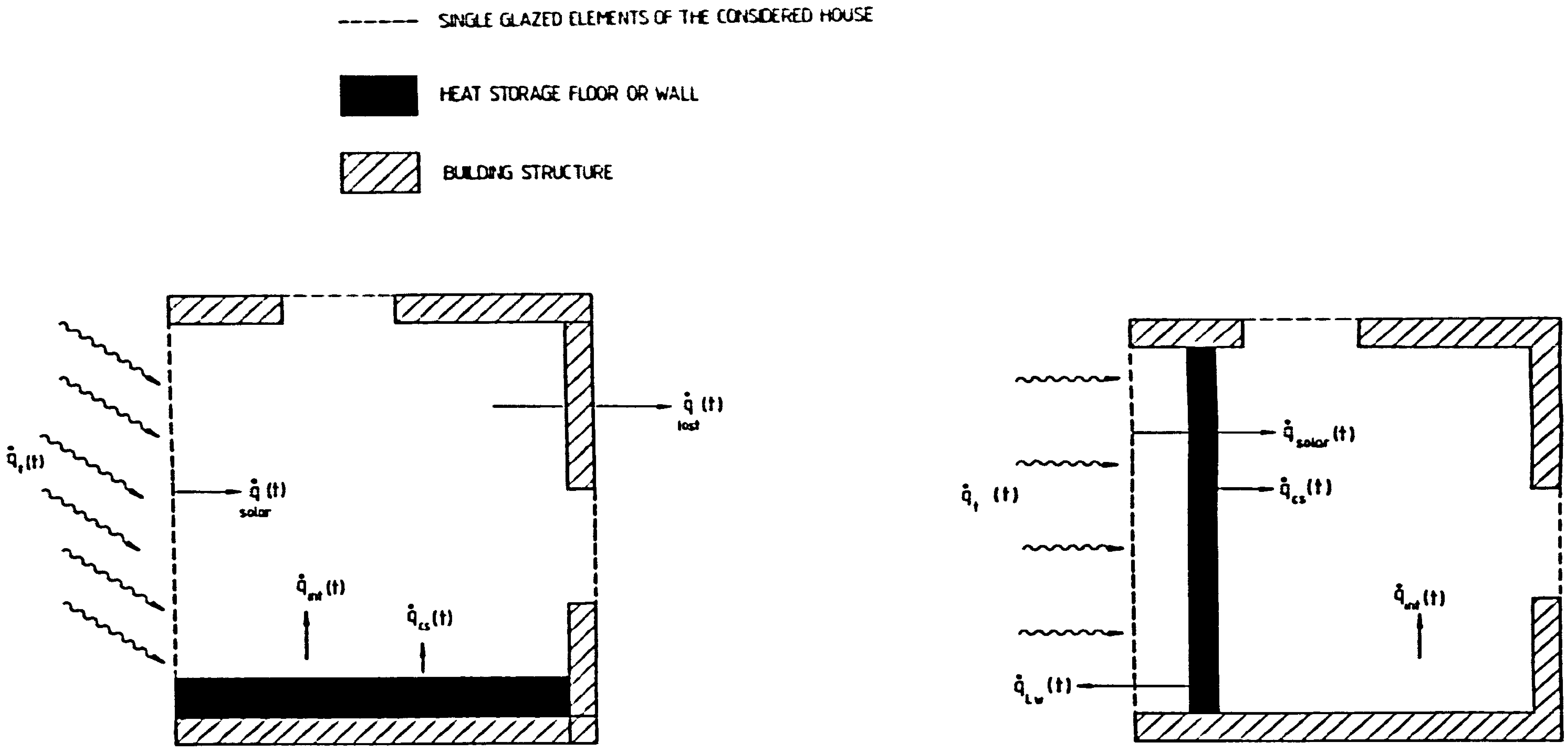
Assuming that the total thermal mass of the solid walls and roof of the considered house is negligible relative to that of the storage element {19-20}, then the heat balance equation for the system shown in Figure 2 can be written during the day-time as:

$$(mC)_s \left(dT_s(t_d)/dt_d\right) = \dot{q}_{solar}(t_d) - \dot{q}_{Lost}(t_d) - \dot{q}_{cs}(t_d) + \dot{q}_{int}(t_d) \qquad \ldots (8)$$

During the night-time, equation (8) reduces to:

$$(mC)_s \left(dT_s(t_n)/dt_n\right) = - \dot{q}_{cs}(t_n) - \dot{q}_{Lost}(t_n) + \dot{q}_{int}(t_n) \qquad \ldots (9)$$

where $(mC)_s$ is the heat capacity of the storage element; $T_s(t_d)$ and $T_s(t_n)$ are respectively the storage temperatures during day and night times. The physical relations for the various rates of equations (8) and (9) are defined as follows.




(a) DIRECT - GAIN SYSTEM

(b) UN-VENTED TROMBRE WALL SYSTEM

FIG. 2 SCHEMATIC DIAGRAM OF DIRECT-GAIN AND TROMBRE WALL PASSIVE-HEATING SYSTEMS

The rate of solar energy transmitted to the living space, $\dot{q}_{solar}(t_d)$, is defined by

$$\dot{q}_{solar}(t_d) = A_C(\bar{\tau}\alpha)\,\dot{q}_t(t_d)\,g(t_d) \qquad \dots (10)$$

where $A_C$ is the area of the south-facing glazing, $(\bar{\tau}\alpha)$ is the monthly average glass transmittance-storage element absorptance product, and $\dot{q}_t(t_d)$ is the rate of solar-energy falling per unit area on the vertical south-facing glazing. The dimensionless parameter, $g(t_d)$, used in equation (10) expresses the ratio of the solar energy transmitted through the east, west, and north-facing windows in terms of that transmitted through the south-facing glazing, i.e.

$$g(t_d) = \left(1 + \frac{\sum_{i=1}^{3} A_{win,i}\,q_{t,i}(t_d)}{A_C\,\dot{q}_t(t_d)}\right) \qquad \dots (11)$$

where $A_{win,i}$ is the total window area in the ith direction (for which i=1, 2 or 3 for east, west, or north respectively); and $\dot{q}_{t,i}(t_d)$ is the corresponding rate of solar energy falling on the vertical house walls. The dimensionless parameter, as defined by equation (11), is unity for a simple direct-gain house, i.e., glazed on the south-facing wall only.

The rates of heat loss during the day time, $\dot{q}_{Lost}(t_d)$ and during the night time, $\dot{q}_{Lost}(t_n)$ respectively account for the fabric, the ground and ventilation heat losses: the fabric heat losses being through the walls, roof and floors, and windows (including the south-facing glazing). In general the day-time and the night-time rates of heat loss are defined by:

$$\dot{q}_{Lost}(t_d) = (UA)_h\left(T_i(t_d) - T_a(t_d)\right) \qquad \dots (12)$$

$$\dot{q}_{Lost}(t_n) = (UA)_h\left(T_i(t_n) - T_a(t_n)\right) \qquad \dots (13)$$

where $T_i(t_d)$ and $T_i(t_n)$ are respectively the day-time and night-time indoor air temperatures

$T_a(t_d)$ and $T_a(t_n)$ are respectively the day-time and night-time outdoor ambient environment air temperatures

and $(UA)_h$ is the overall thermal conductance of the considered house defined by equation (3).

The rates of energy conduction during the day-time, $\dot{q}_{cs}(t_d)$ and during the night-time, $\dot{q}_{cs}(t_n)$, are defined as the product of the thermal conductance of the storage, $U_s\ A_s$, and the difference between the storage and the thermostat-set temperatures {20-22}, i.e.

$$\dot{q}_{cs}(t_d) = (U_s\ A_s)\left(T_s(t_d) - T_c\right) \qquad \ldots (14)$$

$$\dot{q}_{cs}(t_n) = (U_s\ A_s)\left(T_s(t_n) - T_c\right) \qquad \ldots (15)$$

where $A_s$ is the effective area of the storage element; $T_s(t_d)$ and $T_s(t_n)$ are respectively representative of the day-time and night-time storage temperatures.

The heat-transfer coefficient from the store to the room air, $U_s$, is defined by {17}

$$U_s = \left((U_i\ k)/(k + d\ U_i)\right) \qquad \ldots (16)$$

where $U_i$ is the heat-transfer coefficient between the inner surface of the storage element and the indoor space. A typical value for $U_i$ is 8.3 W $m^{-2}\,{}^{\circ}C^{-1}$ {22}. The parameters k and d are respectively the thermal conductivity and thickness of the storage element: values for these are listed for the storage floor and walls used in the Yemeni buildings in Table 1.

The last terms on the right hand sides of equations (8) and (9) represent respectively the contributions of the internal energy sources during day-time and night-time. They arose from the operation of lights, stoves, appliances and the presence of occupants and can be expressed {23} on a daily basis, in MJ/day, in terms of storage floor area as

$$\int_{day} \dot{q}_{int}(t_d)\ dt_d + \dot{q}_{int}(t_n)\ dt_n = (0.13 \times 3.6)A_F \qquad \ldots (17)$$

AVERAGE DIURNAL PERFORMANCE

Equation (8) and consequently equation (9) cannot be solved analytically because $\dot{q}_{solar}(t_d)$, $\dot{q}_{Lost}(t_d)$ and $\dot{q}_{Lost}(t_n)$ are complicated functions of both the design characteristics of the house and the weather variables. However, an analytical solution is possible if the difference between the rates of the energy input, $\dot{q}_{solar}(t_d)$ and the energy output, $\dot{q}_{Lost}(t_d)$, is assumed to be related to the amount of solar energy input via the dimensionless parameter, $f(t_d)$, i.e.

$$f(t_d)\ \dot{q}_{solar}(t_d) = \dot{q}_{solar}(t_d) - \dot{q}_{Lost}(t_d) \qquad \ldots (18)$$

where $f(t_d)$ is a dimensionless parameter which indicates the net amount of direct gain that is actually used in reducing the house energy load. It will be established, in Section 3, that the average daily value of $f(t_d)$, namely $\bar{F}$, is related to the daily average critical radiation ratio, $\bar{X}_c$, defined by equation (5).

The next step in finding an analytical solution for equation (8) assumes that:

i) the solar insolation falling on any south-facing passive collector can be treated as invariant throughout the day; and

ii) the day-time plus the night-time transient rates of heat losses can be expressed in terms of the 24-hour average steady-state rate of heat losses.

The replacement of the time-dependent insolation by a constant daily rate $(\bar{Q}_{solar}/n_d)$, will not influence the amount of heat conducted from the storage during day-time {19-21}. For low values of the thermal time constant,

$$\tau_s = (mC)_s/U_s \ ,$$

the effect of the above assumption on the amount of heat collected by room air during the night is within the allowed limits of error (i.e. 6% - see reference {19} ). Better agreements were found by increasing the values of $\tau_s$ and at large values, i.e. $\tau_s \geqslant 5$ hours, the effect of the first assumption is negligible. Accordingly, by using storage elements with $\tau_s \geqslant 5$ hours, the replacement of the time-dependent insolation by a constant daily rate will not effect the predictions of the analysis. The transient rates of heat loss from the structure and the glazed elements of the residential buildings in the Yemen can be expressed in terms of the corresponding steady-state rates of heat loss by employing a heat-loss reduction factor of 0.71 in the summer and 0.79 in the winter {24}. Consequently the transient rate of heat loss,

$$\dot{q}_{Lost}(t) = \dot{q}_{Lost}(t_d) + \dot{q}_{Lost}(t_n),$$

can be expressed in terms of the corresponding steady-state rate of heat loss, $\dot{\bar{Q}}_{Lost}$, via the equation

$$\dot{q}_{Lost}(t) = \bar{R}\,\dot{\bar{Q}}_{Lost} \qquad \dots (19)$$

where $\bar{R}$ is the 24-hour average of the heat-loss reduction factor, $R(t)$ - see reference {24}. Thus the effect of substituting for the transient rate of heat loss by the corresponding steady-state one can be eliminated by multiplying the steady-state rate of heat loss, $\dot{\bar{Q}}_{Lost}$ by the 24-hour average of the heat loss reduction factor. With these justifications, equations (8) and (9) can respectively be rewritten as:

$$(mC)_s \left(dT_s(t_d)/dt_d\right) = \bar{F}\left(\bar{Q}_{solar}/n_d\right) - \dot{q}_{cs}(t_d) \quad \dots (20)$$

$$(mC)_s \left(dT_s(t_n)/dt_n\right) = -\dot{q}_{cs}(t_n) \qquad \dots (21)$$

where $\bar{Q}_{solar}$ and $\dot{\bar{Q}}_{Lost}$ are respectively the daily average values of the solar input and the overall steady-state rate of house heat loss, i.e. fabric plus ventilation and ground heat losses, $n_d$ is the day-time duration of sunshine in seconds, and $\bar{F}$ is the daily average value of the dimensionless direct solar-gain parameter, $f(t_d)$. In equation forms $\bar{Q}_{solar}$, $\dot{\bar{Q}}_{Lost}$ and $\bar{F}$ are respectively given by:

$$\bar{Q}_{solar} = A_c(\bar{\tau\alpha})\,\bar{H}_T\,\bar{g} \qquad \dots (22)$$

$$\bar{\dot{Q}}_{Lost} = (UA)_h\left(\bar{T}_t - \bar{T}_a\right) \qquad \ldots (23)$$

$$\bar{F} = \left(1 - (\Delta t)\bar{R}\ \bar{\dot{Q}}_{Lost}/\bar{Q}_{solar}\right) \qquad \ldots (24)$$

where $\bar{H}_T$ is the daily average amount of solar radiation falling per unit area on the south-facing glazing, and $\bar{g}$ is the daily average value of $g(t_d)$ defined by:

$$\bar{g} = \left(1 + \frac{\sum_{i=1}^{3} A_{win,i}\ \bar{H}_{T,i}}{A_c\ \ \bar{H}_T}\right) \qquad \ldots (25)$$

$\bar{H}_{T,i}$ is the average per day of the amount of solar radiation falling per unit area on the house walls located in the east, west, and north. We evaluate, see Eq.(23), the steady-state rate of heat loss, $\dot{Q}_{Lost}$, with respect to a reference indoor temperature, $\bar{T}_r$, rather than with respect to the fixed thermostat set temperature. This technique allows for the contribution of the internal gains in reducing the house load. The reference temperature, $\bar{T}_r$, is related to $T_c$ by:

$$\bar{T}_r = \left(T_c - \bar{Q}_{int}/(\Delta t(UA)_h\right) \qquad \ldots (26)$$

where $\bar{Q}_{int}$ is given by equation (17).

The solutions of equations (20) and (21), taking into consideration equations (22) through to (26), yields for the day-time and night-time storage temperatures the following expressions respectively:

FOR DIRECT-GAIN SYSTEM

During the day-time

$$\left(T_{sd}(t_d) - T_c\right) = \left(\bar{F}\ \bar{Q}_{solar}/\ n_d\ U_{sd}\right)\left(1 - \exp\left(-\ t_d/\tau_{sd}\right)\right)$$

$$+ \left(T_{sd}(0) - T_c\right) \exp\left(-\ t_d/\tau_{sd}\right) \qquad \ldots (27)$$

During the night-time

$$\left(T_{sd}(t_n) - T_c\right) = \left(T_{sd}(n_d) - T_c\right) \exp\left(- t_n/\tau_{sd}\right) \qquad \ldots (28)$$

where $T_{sd}(0)$ and $T_{sd}(n_d)$ are respectively the storage temperatures at the beginning, i.e. at $t_d = 0$, and the end of the day, i.e. $t_d = n_d$, and $\tau_{sd}$ is the thermal time constant for the direct-gain storage floor as given by:

$$\tau_{sd} = \left((mC)_{sd}/U_{sd}\right) \qquad \ldots (29)$$

For the un-vented Trombe wall system, see Fig. 2b, the heat absorbed by the heat-storage wall is conducted to the living space or simultaneously lost to the ambient environment. Thus equations (20) and (21) will respectively be modified as:

$$(m\ C)_{sw} \left(dT_{sw}(t_d)/dt_d\right) = \bar{F}\left(\bar{Q}_{solar}/n_d\right) - \dot{q}_{cs}(t_d) - \dot{q}_{Lw}(t_d) \quad .. (30)$$

$$(m\ C)_{sw} \left(dT_{sw}(t_n)/dt_n\right) = - \dot{q}_{cs}(t_n) - \dot{q}_{Lw}(t_n) \qquad \ldots (31)$$

where $\dot{q}_{Lw}(t_d)$ and $\dot{q}_{Lw}(t_n)$ are respectively defined by:-

$$\dot{q}_{Lw}(t_d) = \bar{U}_L A_s \left(T_{sw}(t_d) - T_c\right) \qquad \ldots (32)$$

$$\dot{q}_{Lw}(t_n) = \bar{U}_L A_s \left(T_{sw}(t_n) - T_c\right) \qquad \ldots (33)$$

where $\bar{U}_L$ is the average heat-transfer coefficient from the outer heat storage wall surface through the glazing to the ambient environment: typically $\bar{U}_L = 3.8\ W\ m^{-2}\ C^{-1}$ {22}. The solution of equations (30) and (31) will give the following expressions for the day and night time storage temperatures respectively of the un-vented Trombe wall passive heating system:

During the day time

$$\left(T_{sw}(t_d) - T_c\right) = \bar{F}\left(\bar{Q}_{solar}/n_d(U_{sw} + \bar{U}_L)\right)\left(1 - \exp(- t_d/\tau_{sw})\right)$$
$$- \left(\bar{U}_L/(U_{sw} + \bar{U}_L)\right)\left(T_c - \bar{T}_a\right)\left(1 - \exp(- t_d/\tau_{sw})\right)$$
$$+ \left(T_{sw}(0) - T_c\right) \exp( - t_d/\tau_{sw}) \quad \ldots (34)$$

During the night time

$$\left(T_{sw}(t_n) - T_c\right) = - \left(\bar{U}_L/(U_{sw} + \bar{U}_L)\right)\left(T_c - \bar{T}_a\right)\left(1-\exp(- t_n/\tau_{sw})\right)$$
$$+ \left(T_{sw}(n_d) - T_c\right) \exp(- t_n/\tau_{sw}) \quad \ldots (35)$$

where $\tau_{sw}$ is the time thermal constant for the south-facing un-vented Trombe wall, and defined as:

$$\tau_{sw} = \left((m\ C)_{sw}/(U_{sw} + \bar{U}_L)\right) \quad \ldots (36)$$

On a daily basis, the total energy (including the incidental gains) transferred to the room air during the day-time and night-time are respectively:

FOR THE DIRECT-GAIN SYSTEM

During the day time

$$\bar{Q}_{dd} = (1 - \bar{F})\,\bar{Q}_{solar} + \int_0^{n_d} U_{sd}\left(T_{sd}(t_d) - T_c\right) dt_d \quad \ldots (37)$$

During the night time

$$\bar{Q}_{nd} = \int_0^{n_n} U_{sd}\left(T_{sd}(t_n) - T_c\right) dt_n \quad \ldots (38)$$

FOR THE UN-VENTED TROMBE WALL SYSTEM

During the day time

$$\bar{Q}_{dw} = (1 - \bar{F}) \left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \bar{Q}_{solar} + \int_0^{n_d} U_{sw}\left(T_{sw}(t_d) - T_c\right) dt_d \quad \ldots (39)$$

During the night time

$$\bar{Q}_{nw} = \int_0^{n_n} U_{sw}\left(T_{sw}(t_n) - T_c\right) dt_n \quad \ldots (40)$$

Substituting from equations (27), (28), (34) and (35) into equations (37), (38), (39) and (40) respectively and integrating the latter equations yield for the energy transferred to the room air during the day-time and night-time the following expressions respectively:

For the Direct-Gain System

During the day time

$$\bar{Q}_{dw} = \bar{Q}_{solar}\left(1 - \bar{F}\left(\tau_{sd}/n_d\right)\left(1 - \exp(- n_d/\tau_{sd})\right)\right)$$
$$+ \tau_{sd} U_{sd}\left(T_{sd}(0) - T_c\right)\left(1 - \exp(- n_d/\tau_{sd})\right) \quad \ldots (41)$$

During the night time

$$\bar{Q}_{nd} = \left(1 - \exp(- n_n/\tau_{sd})\right)\left(\bar{Q}_{solar}\, \bar{F}\left(\tau_{sd}/n_d\right)\left(1 - \exp(-n_d/\tau_{sd})\right)\right)$$
$$+ \left(1 - \exp(- n_n/\tau_{sd})\right)\left(\tau_{sd} U_{sd}\left(T_{sd}(0) - T_c\right) \exp(- n_d/\tau_{sd})\right) \quad \ldots (42)$$

FOR THE UN-VENTED TROMBE WALL SYSTEM

During the day time

$$\bar{Q}_{dw} = \left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \bar{Q}_{solar}\left(1 - \bar{F}(\tau_{sw}/n_d)\left(1 - \exp(-n_d/\tau_{sw})\right)\right)$$

$$+ \quad \tau_{sw} U_{sw} \left(T_{sw}(0) - T_c\right)\left(1 - \exp(-n_d/\tau_{sw})\right) \qquad \ldots (43)$$

During the night time

$$\bar{Q}_{nw} = \left(1 - \exp(-n_n/\tau_{sw})\right)\left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \bar{Q}_{solar}\left(\bar{F}(\tau_{sw}/n_d)(1 - \exp(-n_d/\tau_{sw})\right)$$

$$+ \left(1 - \exp(-n_n/\tau_{sw})\right) \tau_{sw} U_{sw} \left(T_{sw}(0) - T_c\right) \exp(-n_d/\tau_{sw})$$

$$\ldots (44)$$

Equations (41) through to (44) have terms which represent the fraction of $\bar{Q}_{solar}$ which is used profitably on the same day, and the fraction of $\bar{Q}_{solar}$ which remains in storage. Because day-to-day carry over is not considered in this analysis, then the residual energy, i.e. that fraction of $\bar{Q}_{solar}$ which remains in the store and not put into use on that same day can be determined by evaluating the energy transferred into the room air during day-time and night-time i.e. equations (41) through to (44), at $T_s(0) = T_c$ and subtracting the sum from the total solar input. The result of this process gives for the residual energy, $\bar{Q}_R$, the following expressions:-

FOR THE DIRECT-GAIN SYSTEM

$$\bar{Q}_R = \bar{Q}_{solar} - \left(\bar{Q}_{dd} + \bar{Q}_{nd}\right)_{T_{sd}(0)=T_c} = \bar{Q}_{solar}\ \bar{F}(\tau_{sd}/n_d)\left(\exp(-n_n/\tau_{sd})\right) \times$$

$$\times\left(1 - \exp(-n_d/\tau_{sd})\right)$$

$$\ldots (45)$$

FOR THE UN-VENTED TROMBE WALL SYSTEM

$$\bar{Q}_R = \left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \bar{Q}_{solar} - \left(\bar{Q}_{dw} + \bar{Q}_{nw}\right) T_{sw}(0) = T_c$$

$$= \left(U_{sw}/(_{sw} + \bar{U}_L)\right) \bar{Q}_{solar} \; \bar{F}(\tau_{sw}/n_d) \exp(- n_n/\tau_{sw}) \left(1 - \exp(- n_d/\tau_{sw})\right) \quad \ldots (46)$$

Consequently, the average useful day-time and night-time energy-gains are respectively for direct-gain and Trombe heat-storage wall systems:

FOR THE DIRECT-GAIN SYSTEM

During the day time

$$\bar{Q}_{udd} = \bar{Q}_{solar} \left[1 - \frac{\bar{F}(\tau_{sd}/n_d) \left(1 - \exp(- n_d/\tau_{sd})\right)\left(1 - \exp(- n_n/\tau_{sd})\right)}{\left(1 - \exp(-(n_d + n_n)/\tau_{sd})\right)}\right] \quad \ldots (47)$$

During the night time

$$\bar{Q}_{und} = \bar{Q}_{solar} - \bar{Q}_{udd} \quad \ldots (48)$$

FOR THE UN-VENTED TROMBE WALL SYSTEM

During the day time

$$\bar{Q}_{udw} = \bar{Q}_{solar}\left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \left[1 - \frac{\bar{F}(\tau_{sw}/n_d) \left(1 - \exp(- n_d/\tau_{sw})\right)\left(1 - \exp(- n_n/\tau_{sw})\right)}{\left(1 - \exp(-(n_d + n_n)/\tau_{sw})\right)}\right] \quad \ldots (49)$$

During the night time

$$\bar{Q}_{unw} = \left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \bar{Q}_{solar} - \bar{Q}_{udw} \quad \ldots (50)$$

Defining respectively the dimensionless parameters of equations (47) and (49) as the direct-gain ambient-energy recuperation factor, $\eta_{rec,d}$, and the Trombe-wall ambient-energy recuperation factor, $\eta_{rec,w}$, then equations (47) and (49) respectively can be rewritten as:

$$\bar{Q}_{udd} = \eta_{rec,d}\, \bar{Q}_{solar} \qquad \ldots (51)$$

and

$$\bar{Q}_{udw} = \left(U_{sw}/(U_{sw} + \bar{U}_L)\right) \eta_{rec,w}\, \bar{Q}_{solar} \qquad \ldots (52)$$

where $\eta_{rec,d}$ and $\eta_{rec,w}$ are respectively the direct-gain ambient-energy and the Trombe wall ambient-energy recuperation factors defined by:

$$\eta_{rec,d} = \left(1 - \bar{F}\, g_{sd}\right) \qquad \ldots (53)$$

and

$$\eta_{rec,w} = \left(1 - \bar{F}\, g_{sw}\right) \qquad \ldots (54)$$

where $\bar{F}$ is the daily average of the dimensionless direct solar-gain factor, $f(t_d)$, defined by equation (25), and $g_{sd}$; $g_{sw}$ are dimensionless storage parameters defined respectively for the direct-gain and the un-vented Trombe wall systems by:

$$g_{sd} = \left(\frac{(\tau_{sd}/n_d)\left(1 - \exp(-n_d/\tau_{sd})\right)\left(1 - \exp(-n_n/\tau_{sd})\right)}{\left(1 - \exp(-(n_d + n_n)/\tau_{sd})\right)}\right) \qquad \ldots (55)$$

and

$$g_{sw} = \left(\frac{(\tau_{sw}/n_d)\left(1 - \exp(-n_d/\tau_{sw})\right)\left(1 - \exp(-n_n/\tau_{sw})\right)}{\left(1 - \exp(-(n_d + n_n)/\tau_{sw})\right)}\right) \qquad \ldots (56)$$

According to equations (51) and (52), the physical significance of the ambient energy factors, $\eta_{rec,d}$ and $\eta_{rec,w}$ is to determine the useful amounts of solar and internal gains that are used in reducing the energy load for the house.

## AUXILIARY ENERGY REQUIREMENTS

The auxiliary energy required by a finite thermal storage capacity house is defined {23} in general by:

$$\bar{Q}_{aux} = \bar{Q}_{Load} - \bar{Q}_{u} \qquad \dots (57)$$

where $\bar{Q}_{Load}$ and $\bar{Q}_{u}$ are respectively the average daily house energy load and the actual amount of the daily average useful solar and internal energy gains. Thus the auxiliary energy required by a finite thermal store direct-gain or un-vented Trombe wall house can be determined by replacing $\bar{Q}_{U}$ in equation (57) by $\bar{Q}_{udd}$ for the direct gain system and by $\bar{Q}_{udw}$ for the un-vented Trombe wall system. Once this amount is known the temperature variations of the indoor temperature with respect to time on a daily basis, are defined {23} as the sum of the daily average ambient air temperature, $\bar{T}_a$, and the daily average temperature increase resulting from solar and internal gains, and the temperature increase or decrease caused by the auxiliary energy used for heating or cooling the house, i.e.

$$\bar{T}_i = \left[ \bar{T}_a + \left( \frac{\bar{Q}_{int} + \bar{Q}_{solar}}{\Delta t \ (UA)_h} \right) + \left( \bar{Q}_{aux}/\bar{Q}_{Load} \right) \left( T_c - \bar{T}_a \right) \right] \qquad \dots (58)$$

## SECTION 3: PHYSICAL MEANINGS OF THE DIMENSIONLESS PARAMETERS USED IN THIS STUDY AND THEIR RELATIONS TO COMMENSURATE ONES OF THE UTILIZABILITY METHOD

The dimensionless parameters used in this analysis have physical significance. For instance, the direct solar-gain factor, $\bar{F}$, measures the critical radiation level at which the solar input equals the house load. On the other hand, the ambient-energy recuperation factor, $\eta_{rec}$, is an indication of the net amount of solar-energy input that is used in reducing the house's energy load. The equations for $\bar{F}$, $\eta_{rec,d}$ and $\eta_{rec,w}$ can respectively be rewritten in slightly modified forms for the purposes of establishing the analogy between $\bar{F}$ and $\bar{X}_c$ and consequently between $\bar{\phi}$ and $\eta_{rec,d}$, or $\eta_{rec,w}$, viz

$$\bar{F} = \left(1 - B\, p\, (\Delta T/\bar{H}_\tau)\right) \quad \text{... (59)}$$

$$\eta_{rec,d} = \left((1 - g_{sd}) + g_{sd}\, B\, p\, (\Delta T/\bar{H}_\tau)\right) \quad \text{... (60)}$$

$$\eta_{rec,w} = \left((1 - g_{sw}) + g_{sw}\, B\, p\, (\Delta T/\bar{H}_\tau)\right) \quad \text{... (61)}$$

where $\Delta T$ is the temperature difference between the thermostat set temperature, $T_c$, and the ambient outside air temperature, and $\bar{H}_\tau$ is the sum of the daily average solar radiation transmitted to the living space through the house windows and the south-facing glazing. It is defined in terms of the daily average solar radiation, $\bar{H}_T$, falling on the south-facing collector as

$$\bar{H}_\tau = \bar{g}\, (\bar{\tau\alpha})\, \bar{H}_T \quad \text{... (62)}$$

The parameter B, used in eqs. (59) through to (61) indicates the thermal design efficiency of the considered house, i.e.,

$$B = \left((UA)_h/A_c\right) \quad \text{... (63)}$$

The dimensionless parameter p used in equations (59) to (61) is defined by

$$p = \left(1 + (\bar{T}_r - T_c)/(T_c - \bar{T}_a)\right) \bar{R} \quad \text{... (64)}$$

where $\bar{R}$ is the 24-hour average of the heat-loss reduction factor {24}. According to equations (59), (60) and (61) the plots of $\bar{F}$, $\eta_{rec,d}$, and $\eta_{rec,w}$ as functions of $(\Delta T/\bar{H}_T)$ will yeild straight lines, see section 4, whose intersections with the $\bar{F}$, $\eta_{rec,d}$ and $\eta_{rec,w}$ axes are respectively unity, $(1-g_{sd})$, and $(1-g_{sw})$. The slopes of these plots give the values of the parameter B, see equations (59) to (61). Thus designers can, by using the presented correlations, determine the thermal design efficiencies of those buildings incorporating direct-gain or un-vented Trombe wall passive-heating systems as well as the values of the storage parameter, which in turn determines the thickness and the heat capacity of the required storage unit.

Unlike the utilizability method, see reference {6}, the present design method is applicable for positive as well as negative temperature differences between the thermostat set temperature and the outside ambient air temperature. For the temperature domain, $T_c > \bar{T}_a$, the $\bar{F}$ factor is related to the monthly average critical radiation ratio, $\bar{X}_c$ - see equation (5), via the relation

$$\bar{F} = (1 - Y \bar{X}_c) \qquad \ldots (65)$$

where Y is a dimensionless constant defined by

$$Y = (R_n/\bar{R}_t)\, r_{tn}\, (\bar{R}/\bar{g}) \qquad \ldots (66)$$

A similar analogy between $\bar{\phi}$ and $\eta_{rec}$ can be obtained. For the temperature domain $T_c > \bar{T}_a$, throughout which the utilizability method is valid, $\eta_{rec,d}$ and $\eta_{rec,w}$ (see equations (53) and (54)) can be approximated respectively by:

$$\eta_{rec,d} = \exp(- g_{sd}) \exp(g_{sd}\, Y\, \bar{X}_c) \qquad \ldots (67)$$

and

$$\eta_{rec,w} = \exp(- g_{sw}) \exp(g_{sw}\, Y\, \bar{X}_c) \qquad \ldots (68)$$

where $g_{sd}$, $g_{sw}$ and $Y$ are given respectively by equations (55), (56) and (66). When equations (67) and (68) are compared respectively with equation (5) it can be seen that:

$$\eta_{rec,d} = \left( \exp(-g_{sd}) \exp\left((g_{sd} Y - Y_1)\right)\bar{X}_c \right) \bar{\phi} \quad \ldots (69)$$

and

$$\eta_{rec,w} = \left( \exp(-g_{sw}) \exp\left((g_{sw} Y - Y_1)\right)X_c \right) \bar{\phi} \quad \ldots (70)$$

where $Y_1$ is a constant defined by:

$$Y_1 = \left(a + b(R_n/\bar{R}_t)\right)\left(1 + c\,\bar{X}_c\right) \quad \ldots (71)$$

For $T_c < \bar{T}_a$, the ambient-energy recuperation factor determines the amount of heat that is in excess of the house load. For such a situation, the house load (see equation (23)) is negative and therefore the daily average value of the direct solar-gain factor, $\bar{F}$, is greater than unity - see equation (24). On the other hand, the ambient-energy recuperation factor, for the temperature domain $T_c < \bar{T}_a$, is negative only if the product of the direct solar-gain factor, $\bar{F}$, and the storage parameter, $g_{sd}$ or $g_{sw}$ exceeds unity. It is clear from equation (53) for a direct gain system, and from equation(54), for the un-vented Trombe wall system, that the auxiliary heating curves, i.e. the plots of $\eta_{rec,d}$ or $\eta_{rec,w}$ versus $\left((T_c - \bar{T}_a)/\bar{H}\,\tau\right)$ for $T_c > \bar{T}_a$, converge to the points

$\bar{F} = 1/g_{sd}$ (for the direct gain system)

and

$F = 1/g_{sw}$ (for the un-vented Trombe wall system).

However, the auxiliary cooling curves, i.e. the plots of $\eta_{rec}$ versus $\left((T_c - \bar{T}_a)/\bar{H}\,\tau\right)$ for $T_c < \bar{T}_a$, converge to the points

$\bar{F} = 2/g_{sd}$ (for the firect-gain system)

and

$\bar{F} = 2/g_{sw}$ (for the un-vented Trombe wall system).

As far as the applications, see section 4 of this analysis, are concerned, we used two approximations: the first sets the value of the ambient-energy recuperation factor equal to unity whenever the value of the direct solar-gain factor is negative. In such a situation, $\bar{F}$ was put equal to zero. In the second approximation, we set the value of $\eta_{rec}$ equal to minus unity whenever the product of $\bar{F}$ and the storage parameter becomes greater than unity. In such a case, the value of $\bar{F}$ is between unity and four. The first approximation resembles that of the utilizability method, where the values of $\bar{\phi}$ were set to unity whenever the values of $\bar{X}_c$ become zero or negative. The limitation of the $\bar{F}$ values in the second approximation, to between unity and four resembles the technique used in the solar-load ratio method, where the ratio of the solar input to the house load was set equal to four whenever it exceeds this value {3}. The justification for both approximations is to be able to compare the predictions of the presented method with those of existing computer simulation studies. It should be emphasised that the above approximations do not restrict the applicability of the present design method.

## SECTION FOUR: APPLICATIONS AND RESULTS

To illustrate the use of the presented design method, we first present a case study for a direct-gain house whose external walls are built either of stone or concrete. These two materials are those most commonly used for external walls in Yemeni dwellings. The monthly-average daily values of the weather data for the considered location, i.e. Sana'a (15$^0$N) are plotted in fig. 1. Using the system parameters listed in Table 1 and the weather data of fig. 1 the values of the direct solar-gain factor and the direct-gain ambient energy recuperation factors are calculated via equations (24) and (53) respectively. The results are correlated with $(\Delta T/\bar{H}_T)$ as shown in figures (3) and (4). Fig. 3 shows the graphical dependence of both the direct solar-gain factor, plotted in the upper part of fig. 3, and the direct-gain ambient-energy recuperation factor, plotted in the lower part of fig. 3, for a single-storey stone house employing a south-facing direct-gain passive heating system. This direct-gain house, assuming a typical house floor area of 220 m$^2$, is characterised by a $B_T$-factor, see equation (63), ranging from 28.6 to 180.4 W per $^0$C per m$^2$ of the area of the south-facing passive collector. In other words, the house's overall average thermal conductance, as calculated by equation (3), ranges assuming a south-facing collector area of 5 to 50 m$^2$, from 0.9 to 1.34 kW $^0C^{-1}$. This rate of heat loss per degree represents the sum of the fabric, ventilation and ground heat losses and therefore it is higher than that calculated by the method of reference {24} where the ground and ventilation heat losses were assumed to be balanced by the internal energy gains. It is clear from fig. 3 that as the collector-to-storage floor areas ratios increased the values of the direct solar-gain factor, $\bar{F}$, decreased in the temperature range $T_c < \bar{T}_a$ while they increased in the temperature range $T_c > \bar{T}_a$. The effect of increasing the collector-to-storage floor areas ratio on the values of the direct-gain ambient energy recuperation factor is exactly the opposite - see the lower part of fig. 3. In practice, this behaviour means that the cooling auxiliary energy requirements are directly proportional, provided a fixed thermostat set temperature, to the collector-to-storage floor areas ratio. For example, the annual cooling auxiliary requirements at a thermostat set temperature of 18$^0$C and a collector-to-storage floor areas ratio of 0.02 is only 0.6 of the auxiliary cooling requirements evaluated at the same thermostat set temperature, but at a

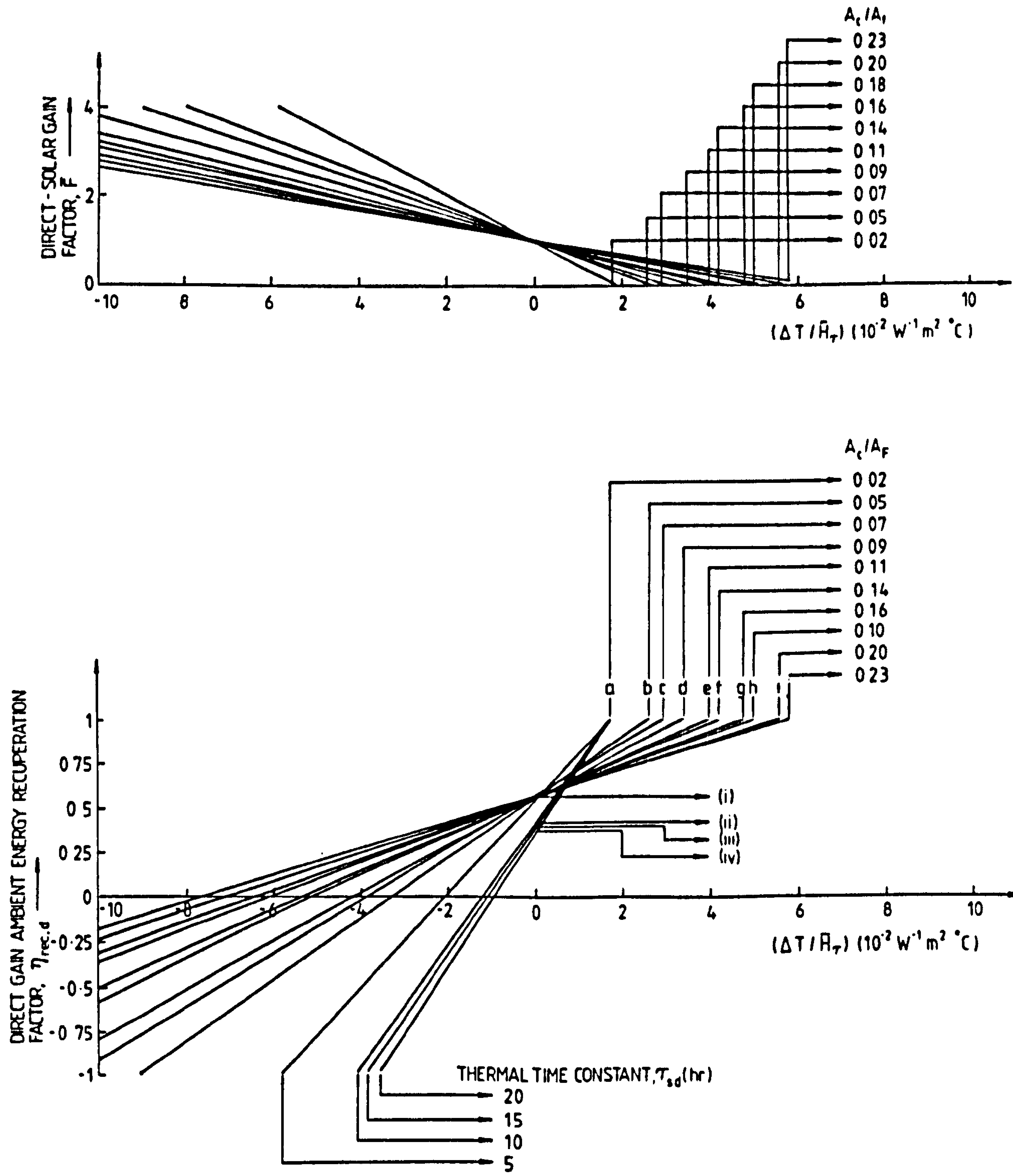



FIG. 3. CORRELATIONS OF THE DIRECT-GAIN AMBIENT ENERGY RECUPERATION FACTOR, $\eta_{rec,d}$, AND OF THE DIRECT-SOLAR GAIN FACTOR, $\bar{F}$, FOR A SINGLE STOREY STONE HOUSE WITH THE THERMOSTAT - OUTDOOR TEMPERATURE DIFFERENCE DIVIDED BY THE TOTAL AMOUNT OF SOLAR RADIATION TRANSMITTED TO THE CONSIDERED HOUSE

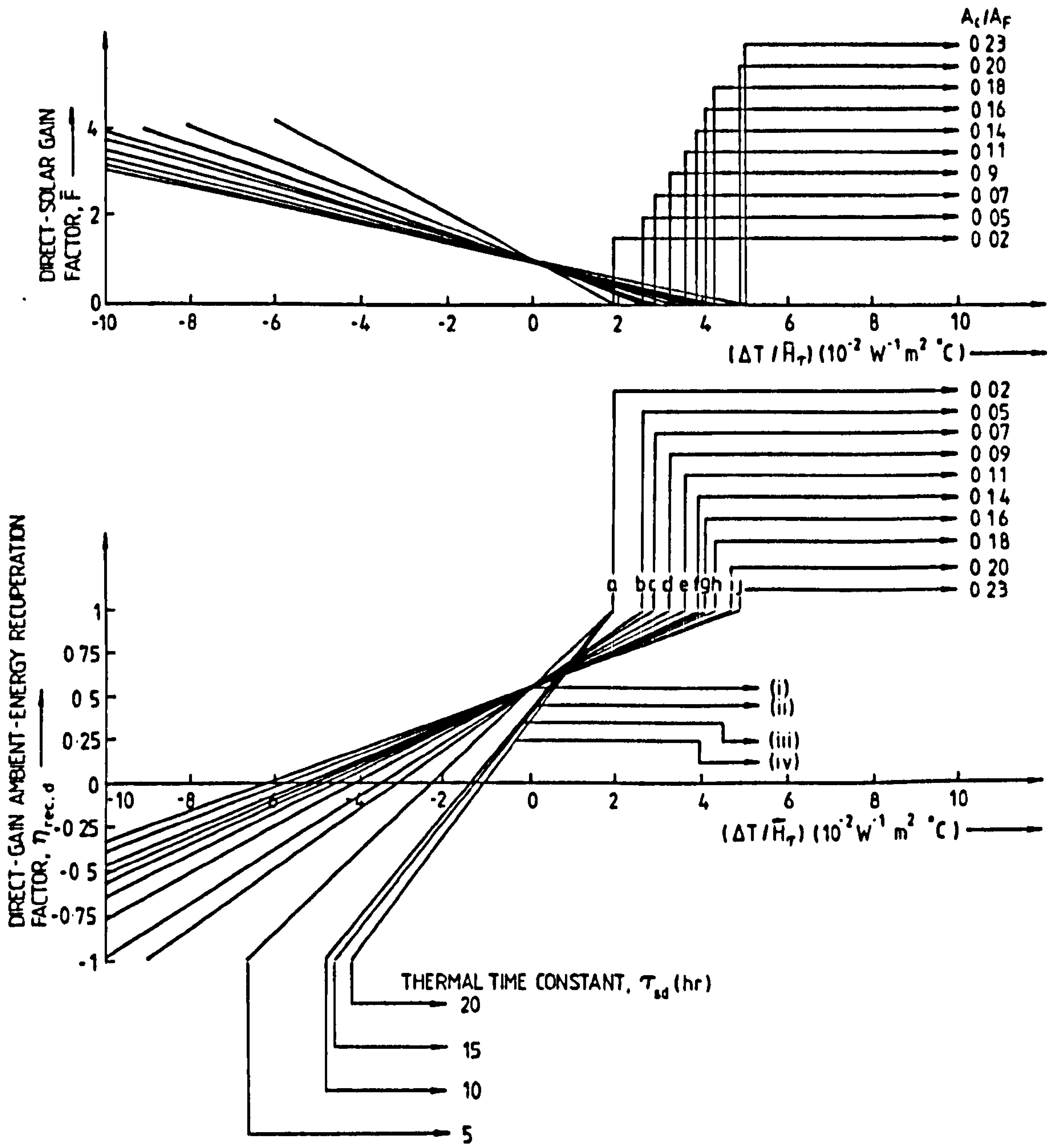



FIG. 4 CORRELATIONS OF THE DIRECT-GAIN AMBIENT-ENERGY RECUPERATION FACTOR, $\eta_{rec,d}$ AND OF THE DIRECT-SOLAR GAIN FACTOR, $\bar{F}$, FOR A SINGLE-STOREY CONCRETE HOUSE WITH THE THERMOSTAT-OUT DOOR TEMPERATURE DIFFERENCE DIVIDED BY THE TOTAL AMOUNT OF SOLAR RADIATION TRANSMITTED TO THE CONSIDERED HOUSE.

collector-to-storage floor areas ratio of 0.2. On the other hand, the increase of the thermal time constant, either by increasing the heat capacity of the storage element or decreasing the heat-transfer coefficient from storage to room air - see equation (16), leads to a decrease, except at the point $\eta_{rec,d} = 1$, in the values of the direct-gain ambient-energy recuperation factor for both $T_c > \bar{T}_a$ and $T_c < \bar{T}_a$ - see the lower part of fig. 3. This behaviour is a direct consequence of the fact that the increase of the thermal time constant corresponds to delaying the release of heat from the storage element to the living space and increasing the values of the storage parameter see equation (55), thereby decreasing the value of the direct-gain ambient-energy recuperation factor. These values with $\eta_{rec,d} = 1$ were not influenced by the increase of the thermal time constant. This is so because we set the value of $\eta_{rec,d}$ equal to unity whenever the product of the direct solar-gain factor, $\bar{F}$, and the storage parameter $g_{sd}$, exceeds unity. This approximation is similar to that of the "Un-utilizability" design method {4} where the values of the monthly average daily utilizability function, $\bar{\phi}$, were set equal to unity whenever the values of $\bar{X}_c$ become smaller or equal to zero. Thus it is possible by changing the thermal time constant to construct a family of $\eta_{rec,d}$ curves which share the point $\eta_{rec,d} = 1$ and intersect with the $\eta_{rec,d}$ axis, depending on the values of the thermal time constant, at different points. These intersection points, see equation (60) give the values of the storage parameter. Once this parameter is known, designers can, for a given geographical location, choose the appropriate thermal properties of the storage unit. The storage parameter can also be obtained by dividing, for a given collector-to-storage floor areas ratio, the slopes of the $\eta_{rec,d}$ factor by the corresponding one for the $\bar{F}$-factor. In fig. 3 the effect of increasing the collector-to-storage floor areas ratio on the behaviour of the direct-gain ambient-energy recuperation factor can be obtained, for a given thermal time constant, by joining points (a) through to (j) with points (i), (ii), (iii) or (iv). On the other hand, the effect of increasing the thermal time constant on the behaviour of the direct-gain ambient-energy recuperation factor can be obtained, at a given collector-to-storage floor areas ratio, by joining point (a) ......, or (j) with points (i) through to (vi). The same results apply to the curves of figure 4 where the non-south-facing walls of the direct-gain house are built of concrete rather than of stone. This change in the building material of the external walls of the direct-gain house increases, assuming the same collector-to-storage floor areas ratio occurs for the stone house, the values of the B-factor from 28.6 to 33.6 and from 180.4 to 185.4 W per $^{\circ}$C per m$^2$ of the south-facing collector area. As a result, the values of the $\bar{F}$-factor were below those of fig. 3 in the temperature domain $T_c > \bar{T}_a$ and above them at $T_c < \bar{T}_a$. The effect of such a change on the direct-gain ambient-energy recuperation factor is illustrated in fig. 5. It is evident, from fig. 5 that the use of relatively dense building materials, e.g. stone for the external walls of the direct-gain house reduces the values of $\eta_{rec,d}$, in the temperature range $T_c > \bar{T}_a$ while it increases them in the temperature domain $T_c < \bar{T}_a$. Practically this means that the auxiliary heating energy of a direct-gain house whose external walls are constructed of stone is smaller than that of a similar direct-gain house but with external walls built of concrete. The opposite case is true for the auxiliary cooling requirements. For example, at a thermostat set temperature of 21$^{\circ}$C and a collector-to-storage floor areas ratio of 0.16, it was found that the annual auxiliary heating requirements of a direct-gain stone house are 0.6 those of a similar direct-gain concrete house. On the contrary, the annual auxiliary cooling requirements, evaluated for the same system parameters, of a single-storey direct-gain stone house were 1.044 times greater than those for a similar single-storey direct-gain concrete house. Thus the use of a relatively dense building material for the external walls of the direct-gain house will improve the houses's thermal efficiency and thereby reduce the amount of auxiliary heating requirements. The disadvantage however lies in the fact that the use of dense building materials, e.g. stone, for external walls of the direct-gain house increases the auxiliary cooling requirements as well as the monthly-average daily variations of the actual indoor temperature. The latter effect, as illustrated in figure 6, is evaluated at a thermostat set temperature of 21$^{\circ}$C, a collect-to-storage floor ratio of 0.16 and a thermal time constant of 5 hours. It is clear that the use of stone for the external walls of the direct-gain house increases the monthly average daily variations of the actual indoor temperature relative to the fixed thermostat set

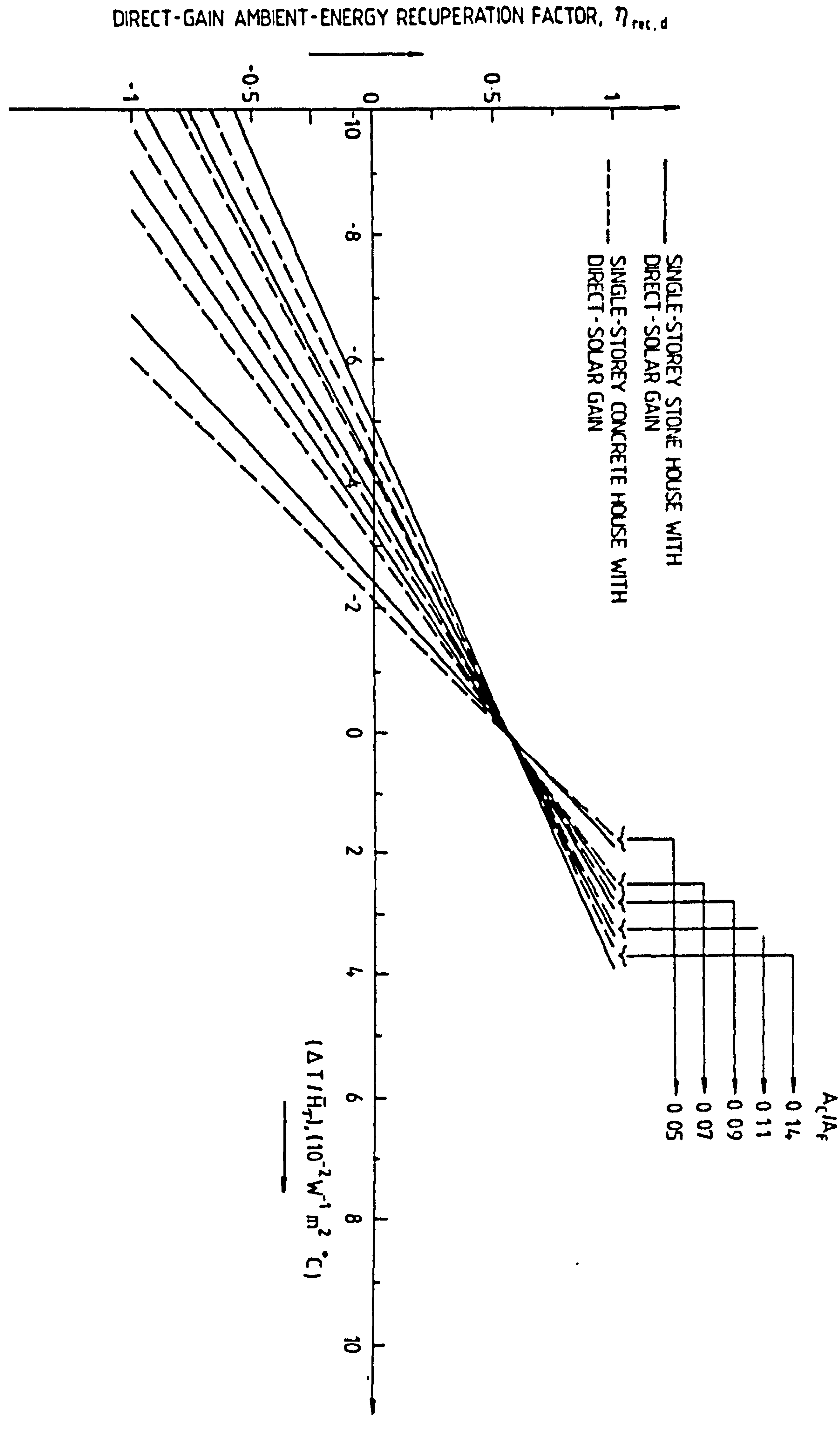



FIG. 5 EFFECT OF HOUSE MASS ON THE DIRECT-GAIN AMBIENT - ENERGY RECUPERATION FACTOR

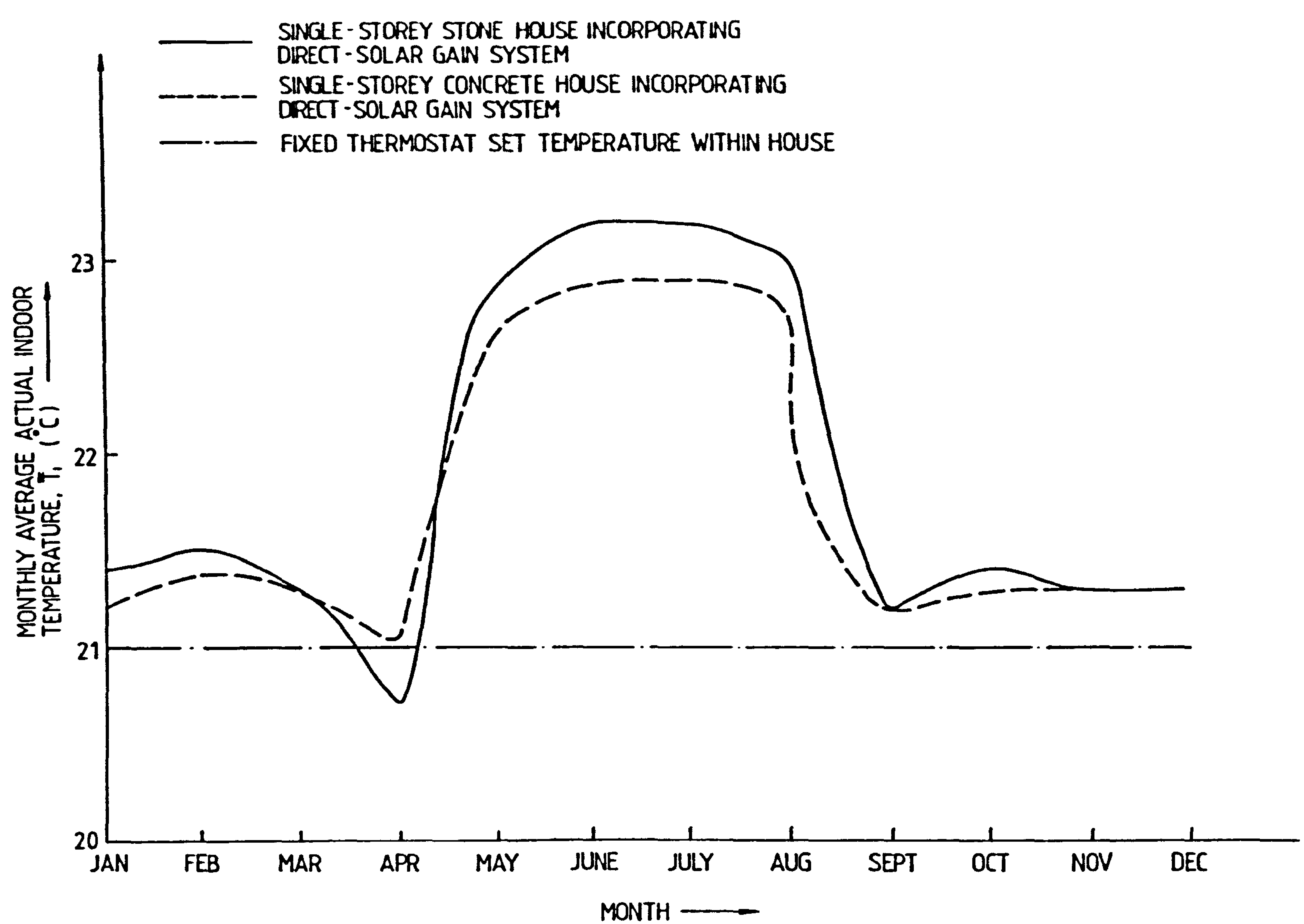



FIG. 6 VARIATIONS OF THE MONTHLY - AVERAGE ACTUAL INDOOR TEMPERATURES OF A SINGLE-STOREY STONE HOUSE AND A SINGLE-STOREY CONCRETE HOUSE BOTH INCORPORATING A SOUTH-FACING PASSIVE-HEATING SYSTEM.

temperature by 0.5 degrees during the winter-time while the increase was 2.5 degrees in the summer-time. For a direct-gain concrete house, the increases in the monthly-average daily variations of the actual indoor temperature were approximately similar to those of a direct-gain stone house during the winter-time and lower by one degree than that of stone during the summer times - see fig. 6.

This behaviour suggests the sizing of the direct-gain system, i.e. finding the values of $T_C$ and $A_C$ at which the auxiliary cooling requirements are minimal and the internal environment is comfortable during the winter and summer. That was accomplished by plotting the fraction of the year during which cooling is required, i.e. the total number of days during which the auxiliary energy requirements were negative divided by the total number of days in a year, as a function of the thermostat set temperature and the collector-to-storage floor area ratio. The results are presented graphically in fig. 7. At thermostat set temperatures smaller than 20°C, this fraction was greater than 0.6 for all collector-to-storage floor areas ratios considered in this analysis. This means that the cooling period exceeds 212 days per year and the incorporation of the direct-gain system will prove to be disadvantageous. Increasing the thermostat set temperatures from 20°to 23°C reduces the duration of the cooling period to a minimum of 73 days per year for all collector-to-storage floor areas ratios. However at a thermostat set temperature of 24°C and a collector-to-storage floor areas ratio of 0.18, the cooling period was almost one month. By increasing the collector-to-storage floor areas ratio to 0.2, the cooling period at a thermostat set temperature of 24°C, increases again to a minimum total of 58 days per year. At thermostat set temperatures greater than 24°C, the cooling period, for the range of the collector-to-storage floor areas ratios considered here, was zero and consequently the direct-gain house needs to be heated for the whole year. It was found, from this analysis, that the annual auxiliary heating requirements at a thermostat set temperature of 25°C and with a south-facing collector area of 50 $m^2$ are 1.4 times greater than those at a thermostat set temperature of 24°C with a collector area of 40 $m^2$. For this reason, we choose the critical design parameters of the direct-gain house, i.e. the values of $T_C$ and $A_C$ at which the auxiliary cooling are minimal, to be 24°C, and 5 to 40 $m^2$

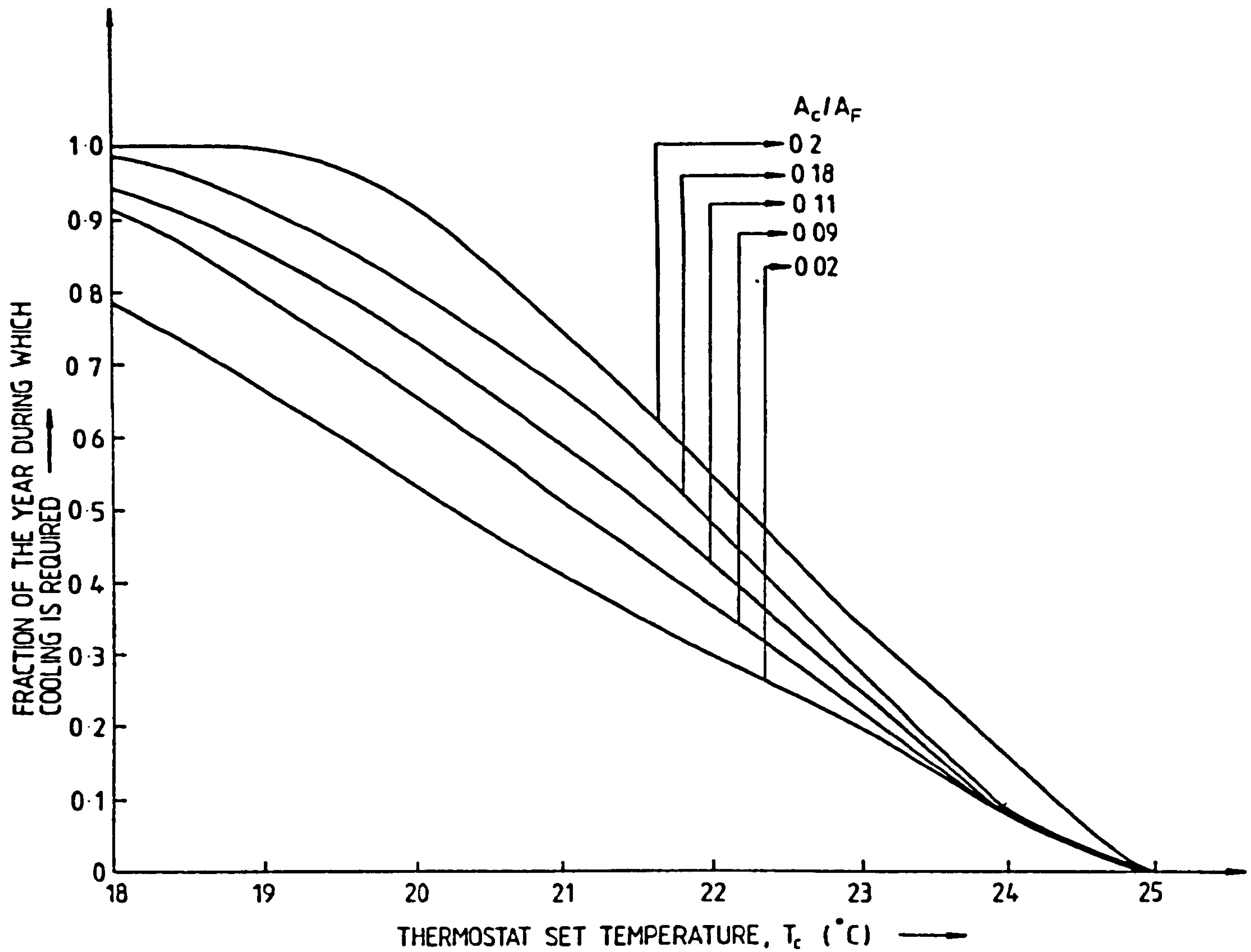



FIG. 7 CORRELATION OF THE ANNUAL COOLING PERIOD WITH THE THERMOSTAT SET TEMPERATURE AND THE COLLECTOR-TO-STORAGE FLOOR-AREAS RATIOS.

respectively. At $T_c$ = 24°C and $A_c$ = 40 m², 98% of the annual auxiliary requirements are for heating while only 2% are needed for cooling during the month of June.

Once the critical design parameters are established, we evaluate the thermal performance of the direct-gain house by calculating the solar fraction, i.e. the ratio of the useful solar input to the house load. The results evaluated at the critical design parameters i.e. $T_c$ = 24°C C,$A_c$ = 40 m² and $\tau_{sd}$ = 25 hours, are presented in fig. 8. Due to the lack of experimental data against which the predictions of this model can ba validated, we choose to compare the predictions, as calculated by the present design method with those of the 'un-utilizability" method which in turn were compared with those of a high-level transient simulation model {4}. The results of the comparisons, in the temperature range $T_c > \bar{T}_a$ are shown in fig. 8. It is clear that the present design method overpredicts the values of the solar heating fraction and consequently underpredicts the amount of auxiliary heating requirements. This is so because of the fact that the definition of the solar-load ratio, as used in this analysis, is different from that of the un-utilizability method. In this analysis, the solar load ratio, SLR, was defined as:

$$SLR = (\bar{\tau}\alpha) \; A_c \; \bar{g} \; \bar{H}_T/\bar{Q}_{Load}$$

where $\bar{g}$ is a dimensionless parameter which measures the amount of solar radiation transmitted through the windows of the direct-gain house relative to that transmitted through the south-facing glazing. The above equation reduces to that of Monsen et. al. {4} by setting $\bar{g}$ equal to unity. The second source of error arose from the definition of the heat capacity of the store. In the "un-utilizability" method the heat capacity of the store was defined as the product of the "effective" heat capacity of the house, which was taken as 123 kJ per degree per square metre of house floor area, and the temperature difference between the low and high thermostat set temperatures. However in this analysis the heat capacity of the store was taken as 506 kJ per degree per square metre of the storage floor area. This corresponds to a thermal time constant of 25 hours and a heat-transfer coefficient from the store to the room air of 5.6 W m$^{-2}$°C$^{-1}$.

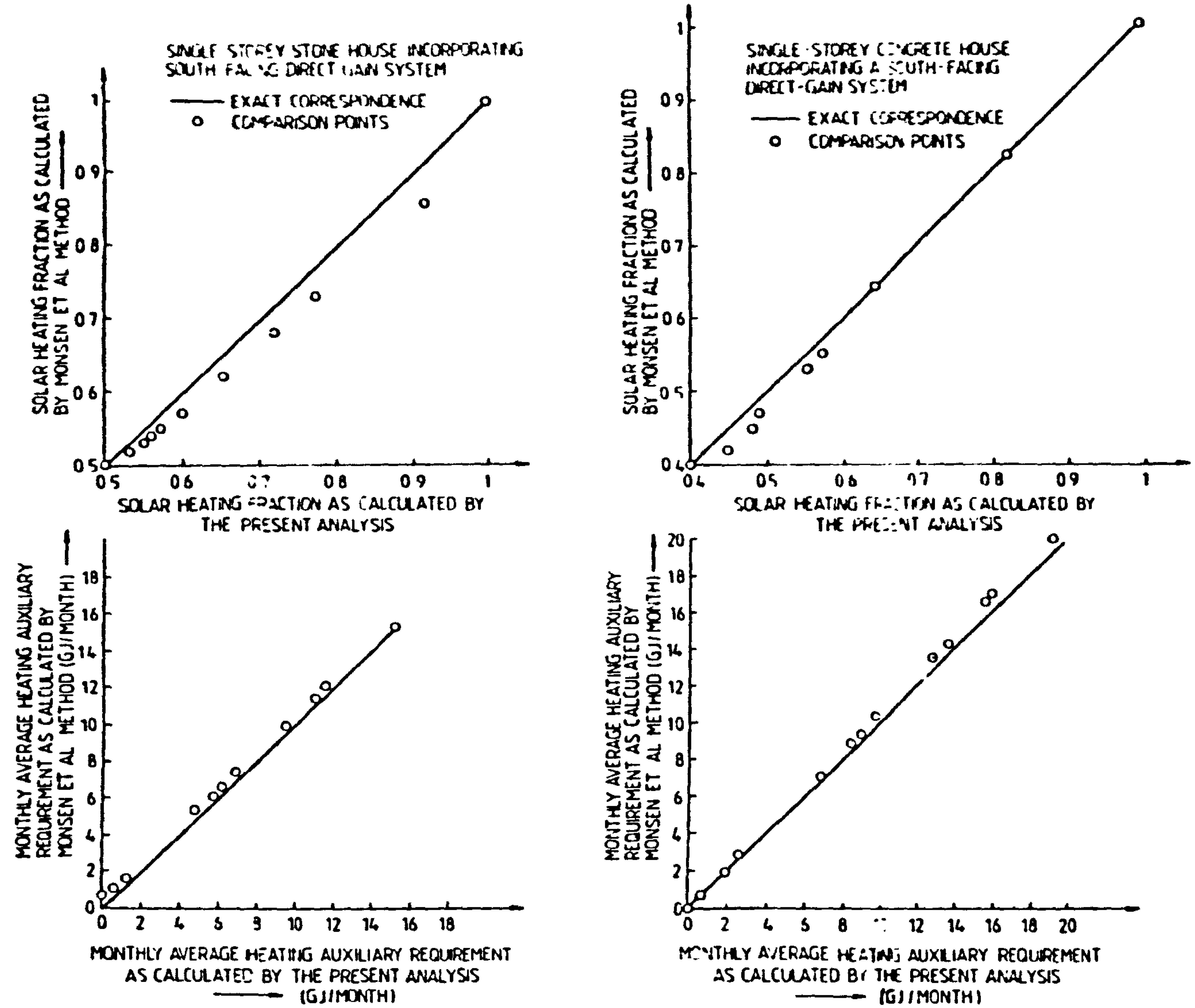



FIG 8 COMPARISON OF THE AUXILIARY ENERGY REQUIREMENTS AND THE SOLAR-HEATING FRACTION CALCULATED BY THE PRESENT DESIGN-MEHOD AND BY THE "UN-UTILIZABILITY" METHOD [4]

## APPLICATIONS TO THE TROMBE WALL SYSTEM

A set of graphs similar to those of figures 3 to 8 can be constructed for houses incorporating un-vented Trombe walls, rather than direct-gain passive heating systems. Because we assumed that the design details of the considered house, except for the thermal properties of the storage elements, are alike in both cases, then the use of the un-vented Trombe wall system in place of the direct-gain one will not affect the values of the $\bar{F}$-factor. However, the values of the ambient energy factor will decrease due to the increase in the thermal time constant. As a result the amount of useful solar gains will be reduced - see equation (52).

Thereby it will be necessary to increase the auxiliary heating requirements, but the use of the un-vented Trombe wall will eliminate the disadvantages of the direct-gain system, such as the large temperature swings, strong directional day lighting, glare, and ultra-violet degradation of the materials within the house. Most importantly, it will preserve the privacy which is of prime concern in Yemeni culture. Upon comparing the thermal performances of both systems, it was found on annual basis that 0.4 of the house load will be provided by solar energy when a single-storey stone house incorporates a south-facing un-vented Trombe wall passive-heating system. This increases, see fig. 8, irrespective of the values of the solar fraction which are greater than or equal to unity, to 0.63 when the same house uses the direct-gain approach for passive heating. For a single-storey concrete house, the annual average of the solar heating fraction is 0.3, when the house incorporates an unvented Trombe wall approach for passive heating compared with 0.53 when the same house uses a direct-gain approach for passive heating.

## CONCLUSIONS

An ambient-energy recuperation factor has been developed as a function of the overall thermal conductance of the house, the total solar and internal gains, and the thermophysical properties of the employed building materials. The correlations of this factor with the thermostat-outdoor temperature differences divided by the monthly average of the daily amounts of solar radiation transmitted to the house are prescribed respectively for heavy and medium thermal-mass houses incorporating south-facing direct-gain passive heating systems. The predictions of the presented design method for the auxiliary heating required per annum by a finite storage capacity direct-gain house agreed to within a 6% error with those deduced using the "un-utilizability" method - see fig. (8). The presented method enables designers to estimate (in addition to the auxiliary heating requirement) the auxiliary requirement for cooling as well as the variation of the actual indoor temperature with time. It also permits the plotting of a number of design graphs which would help designers in tropical climates to choose the most suitable system parameters, such as:- the area of the south-facing glazing, which does not result in overheating of the house; the critical thermostat set temperature at which the auxiliary cooling requirement is a minimum; and the thermal properties of the storage unit.

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# APPENDIX 1

## Arabic-to-English Translation of the 1982 Energy Survey

## INTRODUCTION

The aim of this survey is to estimate the contribution of solar energy in solving the local energy crisis. Surely it is the time to replace the non-renewable energy resources, used in our houses and factories, with the everlasting source of energy "SOLAR ENERGY". Justification of this change over is obvious, namely sunlight is everlasting and free to use. In addition, solar energy solves the problems of the depletion of resources, economic dependency on the oil producing countries, pollution, and the waste hazards associated with the other energy resources as for example with nuclear energy.

We all believe that "Sun is the source of life, so why not use it as a source of energy?".

My confidence in your help and ability to answer the attached group of questions arises from our promise to publish and generalise the results so that every individual can benefit from them. Let us share the introduction of these new concepts and be confident in their potential.

The Researcher
Sana'a University
Faculty of Science
Physics Department
April-1982

# CONTENTS

This questionnaire contains a total of 22 questions distributed as follows:-

| | | |
|---|---|---|
| 1 to 7 | : | General information questions |
| 8 to 18 | : | Fuel use information questions |
| 17 to 21 | : | Water use information questions |

In addition to these there is one question which deals with your opinion regarding the ranking of the low-temperature solar-energy applications according to the urban and rural uses.

## SECTION ONE: General Information Questions

PLEASE COMPLETE THE FOLLOWING QUESTIONS

| | Province | City |
|---|---|---|
| 1) a) Geographical location of your house | ______ | ______ |

| | Children | Adults |
|---|---|---|
| b) Number of family members living in your house | ______ | ______ |

2)

| | | | | |
|---|---|---|---|---|
| a) House location in the city of residence | East | West | North | South |
| b) Dimension of the walls (length x width) (SQ.M.) | East wall | West wall | North wall | South wall |
| c) Dimension of the flat roof (length x width) (SQ.M) | | | | |
| d) Number of house storeys | | | | |
| e) Monthly income (Rial/month) | | | | |

## 3) EFFECT OF OBSTRUCTION ON THE HOUSE WALLS AND ROOF

If your house is surrounded by trees, neighbouring houses, or it has a yard, please complete the following tables.

### a) Trees

Indicate in the following table, the height, location and the distance of the trees from your house walls in the respective directions.

| Direction | Height (m) | Distance from house walls (m) |
|---|---|---|
| East | | |
| West | | |
| North | | |
| South | | |

### b) House yard specifications

Indicate in the following table, the distance between the yard walls and the house walls of your house in the respective directions.

| Direction | Distance (m) |
|---|---|
| East | |
| West | |
| North | |
| South | |

c) Neighbouring house specifications

Indicate in the following table, the number of storeys and the distance between your house or yard walls and those of your neighbouring houses in the respective directions.

| Direction | Number of storeys of neighbouring houses | Distance between your house walls and those of the neighbouring houses (m) | Distance between your yard walls and those of the neighbouring houses (m) |
|---|---|---|---|
| East | | | |
| West | | | |
| North | | | |
| South | | | |

4) TYPE OF EXTERNAL WALL BUILDING MATERIALS

Please mark the appropriate type of masonry materials which are employed in constructing the external walls of each storey of your house.

| Storey Number | Type of masonary material per each storey | | | | | |
|---|---|---|---|---|---|---|
| | Stone | Mud | Red-brick | Concrete | Reinforced Concrete | Combination of more than one material (specify) |
| first storey | | | | | | |
| second storey | | | | | | |
| third storey | | | | | | |
| fourth storey | | | | | | |
| fifth storey | | | | | | |
| sixth storey | | | | | | |
| seventh storey | | | | | | |
| eighth storey | | | | | | |
| ninth storey | | | | | | |
| tenth storey | | | | | | |

5) <u>ROOF EXPOSURE TO THE SUN</u>

Answer the following questions with YES or NO according to the situation of your house roof:

a) is the roof of your house fully exposed to the Sun?

b) is the roof of your house partly exposed to the Sun?

6) <u>WINDOWS EXPOSURE TO THE SUN</u>

Choose the appropriate answers which give the most suitable description for the exposure of your house windows to the Sun. Also indicate the total number of windows and their corresponding total area per each storey.

| Storey | Number of windows exposed to the Sun per each storey | | | | Total number of windows per each storey | Total area of windows per each storey ($M^2$) |
|---|---|---|---|---|---|---|
| | East | West | North | South | | |
| first | | | | | | |
| second | | | | | | |
| third | | | | | | |
| fourth | | | | | | |
| fifth | | | | | | |
| sixth | | | | | | |
| seventh | | | | | | |

7) ROOM SPECIFICATIONS

Please complete the following table taking into considerations the following directions:

Room type: receiving, sitting, sleeping, reading, dining, social gathering, toilets, kitchen and halls

If you have more than one room with the same type or of a type omitted from the above list, please identify them and give their dimensions.

| Room type | Storey at which the room is located | Room dimensions | |
|---|---|---|---|
| | | Length (m) | Width (m) |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
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## SECTION TWO: Fuel Use Information Questions

8) Delete those of the following energy resources which are used in your house.

| |
|---|
| Electricity |
| Wood |
| Natural gas |
| Charcoal |
| Animal waste |
| Agricultural residues |
| Kerosene |

9) ELECTRICITY USE

Delete the functions listed below for which electricity is used in your house.

| |
|---|
| Lighting |
| Cooking |
| Water heating |
| Clothes washing |
| Refrigeration |
| Water distillation |
| House space cooling |
| House space heating |
| Operating household equipment |

10) In front of each one of the following items of equipment, please indicate the number of times per day or week it is used and the approximate duration of each period of use.

| | Number of times each item of equipment is used | | Approximate duration of each use |
|---|---|---|---|
| | per day | per week | (hrs/day) |
| Mud stove | | | |
| Gas oven | | | |
| Electric oven | | | |
| Electric heater (for domestic water heating) | | | |
| Electric heater (for house space heating) | | | |
| Separate immersion heater (for water heating) | | | |
| Water pump | | | |
| Air conditioner (for house space cooling) | | | |
| Ceiling fan | | | |
| Washing machine | | | |
| Food processors | | | |
| Refrigerator | | | |
| Television | | | |
| Radio | | | |
| Others (please specify) | | | |

11) Please indicate in the following table the amount of money you spent per a typical month in winter and a typical month in summer on the following types of fuels.

| | Amount of money spent on fuel (Rial/month) | |
|---|---|---|
| | Summer | Winter |
| Wood/charcoal/animal waste/agricultural residues | | |
| Electricity | | |
| Natural gas | | |
| Kerosene | | |

12) Please review the electricity bills of your house and indicate in the following table the amount of electricity you consumed during a typical month in winter, a typical month in summer and if possible the amount of electricity consumed during the month of fasting.

| Month | Amount of electricity consumed (kW hr/month) |
|---|---|
| | |
| | |
| Month of fasting | |

13) Please indicate in the following table the rated power and the name of the manufacturer of all electrical appliances in your house.

| Appliance | Rated power (W) | Name of manufacturing company |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

14) Wood Use

Delete the functions for which wood is used in your house.

| |
|---|
| Cooking of meat and/or vegetables |
| Bread baking |
| House space heating |
| Domestic water heating |
| Coffee making |
| Others (please specify) |

15) Charcoal Use

| |
|---|
| Cooking of meat and/or vegetables |
| Coffee making |
| House space heating |
| Re-heating pre-prepared food |
| Domestic water heating |
| Others (please specify) |

16) Delete the functions for which Kerosene is used in your house

| |
|---|
| Cooking of meat and/or vegetables |
| Emergency lighting |
| Normal lighting |
| Domestic water heating |
| Coffee making |
| Others (please specify) |

## SECTION THREE: Water Use Information Questions

17) Please answer YES or NO to the following set of questions.

a) Do you have a roof-mounted water-storage tank?
b) Do you have another water-storage tank located either in the first storey of your house or outside the house?
c) Do you use the pressurized main water supply system?
d) Do you pump the water to your roof-mounted water-storage tank?
e) Do you have a potable water well inside your house?

18) Please review the water bills of your house. Indicate in the following table the amount of water consumed during a typical month in winter and a typical month in summer, and the respective costs in those months in Rial.

| Month | Amount of water consumed (please use the unit of capacity you are familiar with) | Cost (Rial/month) |
|---|---|---|
| | ______ litres<br>______ cubic metres<br>______ Tankah | |
| | ______ litres<br>______ cubic metres<br>______ Tankah | |

19) If you have several roof-mounted water-storage tanks, please indicate in the following table the capacity of each tank as well as the number of times it is filled with water during the day or week..

| | Capacity<br>Please use the unit of capacity you are familiar with | Number of times per day or week the roof-mounted storage-tank is filled with water | |
|---|---|---|---|
| | | Day | Week |
| Tank number 1 | ____ litres<br>____ cubic metres<br>____ Tankah | ____ | ____ |
| Tank number 2 | ____ litres<br>____ cubic metres<br>____ Tankah | ____ | ____ |

20) <u>Hot Water Use</u>

Delete the functions for which you use the hot water in your house. Please indicate in front of the deleted function the amount of hot water consumed for that function as measured in either litres, cubic metres, or Tankah per day.

| | Amount of hot water consumed |
|---|---|
| Bathing | |
| Clothes washing | |
| Dish washing | |
| Cleansing before prayers | |
| Others (please specify) | |

21) Please indicate in the following table the capacity and the location of all water-storage tanks present in your house as well as the period for which the stored water in each tank suffices your use in case of emergency stoppages. Please use either litres, cubic metres, or Tankah for the unit of capacity.

| | Location | Capacity | period during which the stored water in each tank suffices the needs of the house |
|---|---|---|---|
| Tank number 1 | | | |
| Tank number 2 | | | |
| Tank number 3 | | | |
| Tank number 4 | | | |

22) Please rank the following low-temperature solar-energy applications according to your perception of their importance for urban and rural usages.

| | Rank on a scale of 1 to 10 (10 being the least important | |
|---|---|---|
| | urban use | rural use |
| Water heating | | |
| Water pumping | | |
| House electrification | | |
| Water distillation | | |
| Crop-drying | | |
| Irrigation | | |
| House space heating | | |
| House space cooling | | |
| Refrigeration | | |

# APPENDIX 2

## Listings of the Computer Programs Used in the Analysis

# SURVEY ANALYSIS COMPUTER PROGRAM

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10 DIM A%(30,20),B%(10,36),A$(30),C(10,17),ETR(10),ETRW(10),A(20)
15 DIM RWA(20),EWA(20),WWA(20),NWA(20),SWA(20),WE1(20),WE2(20),WE3(20)
20 DIM WE4(20),WEW1(20),WEW2(20),WEW3(20),WEW4(20),RA(20),TNW(20),BW(20)
21 DIM EXPW(20),B(5),GWEL(20),CWEL(20),GREL(20),NREL(20),CREL1(20)
22 DIM CREL2(20),EWEL(20),WWEL(20),NWEL(20),SWEL(20),PDPS(5),PDPW(5)
23 DIM BLC(5),MTLS(5),MTLW(5),SLRS(5),SLRW(5),SHFS(5),SHFW(5),AUXS(5)
24 DIM AUXW(5),CS(5),CW(5),AAUXS(5),AAUXW(5),ACS(5),ACW(5),EWLCR(5)
25 DIM NSLCR(5)
26 INPUT "ENTER NAME OF DATA FILE SHR,SDR,WHR,WDR",N$
27 OPEN "I",#1,N$
28 IF N$="END" THEN 36
29 INPUT #1,X
30 FOR Y=6 TO 18
31 INPUT #1,A%(X,Y)
32 NEXT Y
33 PRINT
34 CLOSE #1
35 GO TO 26
36 FOR Y=6 TO 18
37 A%(1,Y)=Y
40 H=(Y-12.5)*(3.14/12)
41 DEC=(2.2)*(3.14/180)
42 LR=(15)*(3.14/180)
50 A%(2,Y)=H
90 TDHR=TDHR+A%(3,Y)
110 TDDR=TDDR+A%(4,Y)
120 EDR=-(A%(3,Y))*(COS(DEC)*SIN(H))
121 PRINT SIN(H)
130 IF EDR<0 THEN EDR=0
140 A%(5,Y)=EDR
150 WDR=(A%(3,Y))*(COS(DEC)*SIN(H))
160 IF WDR<0 THEN WDR=0
170 A%(6,Y)=WDR
180 SDR=(A%(3,Y))*(COS(DEC)*SIN(LR)*COS(H)-SIN(DEC)*COS(LR))
190 IF SDR<0 THEN SDR=0
200 A%(7,Y)=SDR
210 NDR=(A%(3,Y))*(SIN(DEC)*COS(LR)-COS(DEC)*SIN(LR)*COS(H))
220 IF NDR<0 THEN NDR=0
230 A%(8,Y)=NDR
240 HER=A%(5,Y)+(A%(4,Y)/2)
250 A%(9,Y)=HER
260 HWR=A%(6,Y)+(A%(4,Y)/2)
270 A%(10,Y)=HWR
280 HSR=A%(7,Y)+(A%(4,Y)/2)
290 A%(11,Y)=HSR
300 HNR=A%(8,Y)+(A%(4,Y)/2)
310 A%(12,Y)=HNR
320 DER=DER+A%(9,Y)
330 DWR=DWR+A%(10,Y)
340 DSR=DSR+A%(11,Y)
350 DNR=DNR+A%(12,Y)
351 NEXT Y
360 FOR Y=6 TO 18
361 A%(13,Y)=Y
362 H=(Y-12.5)*(3.14/12)
363 A%(14,Y)=H
391 DECW=(-20.9)*(3.14/180)
392 LRW=(15)*(3.14/180)
400 TDHRW=TDHRW+A%(15,Y)
410 TDDRW=TDDRW+A%(16,Y)
411 PRINT SIN(H)
420 EDRW=-(A%(15,Y))*(COS(DECW)*SIN(H))
430 IF EDRW<0 THEN EDRW=0
440 A%(17,Y)=EDRW
450 WDRW=(A%(15,Y))*(COS(DECW)*SIN(H))
460 IF WDRW<0 THEN WDRW=0
470 A%(18,Y)=WDRW
480 SDRW=(A%(15,Y))*(COS(DECW)*SIN(LRW)*COS(H)-COS(LRW)*SIN(DECW))
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490 IF SDRW<0 THEN SDRW=0
500 A%(19,Y)=SDRW
510 NDRW=(A%(15,Y))*(COS(LRW)*SIN(DECW)-COS(DECW)*SIN(LRW)*COS(H))
520 IF NDRW<0 THEN NDRW=0
530 A%(20,Y)=NDRW
540 HERW=A%(17,Y)+(A%(16,Y)/2)
550 A%(21,Y)=HERW
560 HWRW=A%(18,Y)+(A%(16,Y)/2)
570 A%(22,Y)=HWRW
580 HSRW=A%(19,Y)+(A%(16,Y)/2)
590 A%(23,Y)=HSRW
600 HNRW=A%(20,Y)+(A%(16,Y)/2)
610 A%(24,Y)=HNRW
620 DERW=DERW+A%(21,Y)
630 DWRW=DWRW+A%(22,Y)
640 DSRW=DSRW+A%(23,Y)
650 DNRW=DNRW+A%(24,Y)
660 NEXT Y
670 LPRINT TAB(30);"SUMMER DESIGN INTENSITIES IN THE Y.A.R."
680 LPRINT
690 LPRINT"-----------------------------------------------------------------------------"
700 LPRINT TAB(40);"DROVS(KJ/M^2)";TAB(70);"HROVS(KJ/M^2)"
701 LPRINT
710 LPRINT TAB(8);"SOT";TAB(15);"HA";TAB(22);"SH";TAB(29);"DF";
720 LPRINT TAB(36);"EDR";TAB(43);"WDR";TAB(50);"SDR";TAB(57);"NDR";
730 LPRINT TAB(64);"HER";TAB(71);"HWR";TAB(78);"HSR";TAB(85);"HNR"
740 LPRINT
750 FOR Y=6 TO 18
760 FOR X=1 TO 12
770 LPRINT TAB((X-1)*7+8);A%(X,Y);
780 NEXT X
790 NEXT Y
800 LPRINT
810 LPRINT TAB(22);TDHR;TAB(29);TDDR;TAB(64);DER;TAB(71);DWR;
820 LPRINT TAB(78);DSR;TAB(85);DNR
830 LPRINT:LPRINT
840 LPRINT TAB(30);"WINTER DESIGN INTENSITIES IN THE Y.A.R."
850 LPRINT
860 FOR Y=6 TO 18
870 FOR X=13 TO 24
880 LPRINT TAB((X-13)*7+8);A%(X,Y);
890 NEXT X
900 NEXT Y
910 LPRINT
920 LPRINT TAB(22);TDHRW;TAB(29);TDDRW;TAB(64);DERW;TAB(71);DWRW;
930 LPRINT TAB(78);DSRW;TAB(85);DNRW
940 LPRINT "-----------------------------------------------------------------------------"
945 INPUT "ENTER HI";S$
946 OPEN "I",#2,S$
950 FOR I=1 TO 30
960 INPUT #2,A$(I)
970 NEXT I
990 FOR J=1 TO 10
1000 FOR I=1 TO 36
1010 PRINT "INPUT Q1-Q6"
1020 INPUT B%(J,I)
1030 NEXT I
1040 RI=B%(J,31)*(2^2)+B%(J,32)*(2^1)+B%(J,33)*(2^0)
1050 HI=B%(J,34)*(2^2)+B%(J,35)*(2^1)+B%(J,36)*(2^0)
1060 IF RI<HI THEN Z=0:GOTO 1080
1070 Z=RI+HI:GOTO 1090
1080 LPRINT "WRONG COMPINATION"
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1100 LPRINT"------------------------------------------------------------------"
1110 LPRINT TAB (30);"FAMILY INDEX=";J
1120 LPRINT
1121 LPRINT"ROOF INDEX-------------HOUSE INDEX------------ROOF-HOUSE
1122 LPRINT
1123 LPRINT R1;TAB(24);H1;TAB(50);Z
1124 LPRINT:LPRINT
1125 LPRINT"SIDES WHICH ARE BLOCKED FROM THE SUN DURING THE DAY"
1126 LPRINT"E--------------W---------------N-----------------S"
1127 LPRINT
1128 LPRINT B%(J,6);TAB(14);B%(J,7);TAB(29);B%(J,8);TAB(47);B%(J,9)
1129 LPRINT:LPRINT
1130 FOR I=1 TO 12
1140 LPRINT TAB((I-1)*7+2);A$(I);
1150 NEXT I
1151 LPRINT:LPRINT
1152 FOR I=1 TO 12
1153 LPRINT TAB((I-1)*7+2);B%(J,I);
1154 NEXT I
1155 LPRINT:LPRINT
1156 FOR I=13 TO 20
1157 LPRINT TAB((I-13)*7+2);A$(I);
1158 NEXT I
1160 LPRINT:LPRINT
1170 FOR I=13 TO 20
1180 LPRINT TAB((I-13)*7+2);B%(J,I);
1190 NEXT I
1200 LPRINT:LPRINT
1201 FOR I=21 TO 30
1202 LPRINT TAB((I-21)*7+2);A$(I);
1203 NEXT I
1204 LPRINT:LPRINT
1205 FOR I=21 TO 30
1206 LPRINT TAB((I-21)*7+2);B%(J,I);
1207 NEXT I
1208 LPRINT:LPRINT
1210 ESA=B%(J,4)*B%(J,10)*3
1220 WSA=B%(J,4)*B%(J,10)*3
1230 SSA=B%(J,5)*B%(J,10)*3
1240 NSA=B%(J,5)*B%(J,10)*3
1241 TSA=ESA+WSA+NSA+SSA:LPRINT
1242 LPRINT"ESA(M^2)-------WSA(M^2)-------NSA(M^2)-------SSA(M^2)------TSA"
1243 LPRINT
1244 LPRINT ESA;TAB(14);WSA;TAB(27);NSA;TAB(41);SSA;TAB(54);TSA
1245 LPRINT"------------------------------------------------------------------"
1246 LPRINT
1250 IF B%(J,6)=1 THEN ESE=0:GOTO 1270
1260 ESE=ESA*DER
1270 IF B%(J,6)=1 THEN ESEW=0:GOTO 1290
1280 ESEW=ESA*DERW
1290 IF B%(J,7)=2 THEN WSE=0:GOTO 1310
1300 WSE=WSA*DWR
1310 IF B%(J,7)=2 THEN WSEW=0:GOTO 1330
1320 WSEW=WSA*DWRW
1330 IF B%(J,8)=3 THEN NSE=0:GOTO 1350
1340 NSE=NSA*DNR
1350 IF B%(J,8)=3 THEN NSEW=0:GOTO 1370
1360 NSEW=NSA*DNRW
1370 IF B%(J,9)=4 THEN SSE=0:GOTO 1390
1380 SSE=SSA*DSR
1390 IF B%(J,9)=4 THEN SSEW=0:GOTO 1410
1400 SSEW=SSA*DSRW
1401 PRINT ESE,WSE,SSE,NSE
1402 PRINT ESEW,WSEW,NSEW,SSEW
1410 EFHS=ESE+WSE+NSE+SSE
1420 EFHW=ESEW+WSEW+SSEW+NSEW
1438 LPRINT"SOLAR ENERGY FALLING ON THE EXTERIOR WALLS AND ITS DIST"
1439 LPRINT:LPRINT"                    SUMMER                          TOTAL";
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1440 LPRINT"                    WINTER                                          TOT"
1441 LPRINT "ESE              WSE              NSE          SSE                    ESEW";
1442 LPRINT"----------- WSEW-----------NSEW-----------SSEW"
1443 LPRINT
1444 LPRINT ESE;TAB(12);WSE;TAB(24);NSE;TAB(36);SSE;TAB(48);EFHS;TAB(60);
1445 LPRINT ESEW;TAB(72);WSEW;TAB(84);NSEW;TAB(96);SSEW;TAB(108);EFHW
1446 LPRINT"-------------------------------------------------------------------------
1447 LPRINT:T=B%(J,10)
1740 PRINT "INPUT THE STOREY REPEATION"
1750 INPUT X
1760 FOR L=1 TO X
1770 FOR M=1 TO 17
1780 PRINT "INPUT ST MATRIX,ROOM-AREA AND WINDOW AREA MUST INPUTED DIR."
1790 INPUT C(L,M)
1801 NEXT M
1802 RA(L)=C(L,2)*C(L,3)
1803 TNW(L)=C(L,8)
1804 BW(L)=C(L,9)
1805 EXPW(L)=(C(L,8)-C(L,9))
1810 EWA(L)=C(L,4)*C(L,10)*C(L,11)
1811 IF ESA=0 THEN 1830
1820 WE1(L)=(ESE)*(EWA(L)/ESA):WEW1(L)=(ESEW)*(EWA(L)/ESA)
1830 WWA(L)=C(L,5)*C(L,12)*C(L,13)
1835 IF WSA=0 THEN 1850
1840 WE2(L)=(WSE)*(WWA(L)/WSA):WEW2(L)=(WSEW)*(WWA(L)/WSA)
1850 NWA(L)=C(L,6)*C(L,14)*C(L,15)
1855 IF NSA=0 THEN 1870
1860 WE3(L)=(NSE)*(NWA(L)/NSA):WEW3(L)=(NSEW)*(NWA(L)/NSA)
1870 SWA(L)=C(L,7)*C(L,16)*C(L,17)
1871 IF SSA=0 THEN 1890
1880 WE4(L)=(SSE)*(SWA(L)/SSA):WEW4(L)=(SSEW)*(SWA(L)/SSA)
1890 ETR(L)=(.9)*(WE1(L)+WE2(L)+WE3(L)+WE4(L))
1900 ETRW(L)=(.9)*(WEW1(L)+WEW2(L)+WEW3(L)+WEW4(L))
1910 ETH=ETH+ETR(L)
1915 ETHW=ETHW+ETRW(L)
1920 RWA(L)=(EWA(L)+WWA(L)+SWA(L)+NWA(L))
1930 TWA=TWA+RWA(L)
1931 PRINT EWA(L),WWA(L),NWA(L),SWA(L)
1932 PRINT WE1(L),WE2(L),WE3(L),WE4(L)
1933 PRINT WEW1(L),WEW2(L),WEW3(L),WEW4(L)
1934 PRINT ETR(L),ETRW(L),RWA(L)
1940 NEXT L
1941 LPRINT
1942 LPRINT"ENERGY TRANSMITTED TO EACH ROOM IN THE HOUSE IN (KJ/DAY)"
1943 LPRINT
1944 LPRINT"TYPE OF THE ROOM--------TRANSMITTED ENERGY";
1945 LPRINT"-------WINDOW AREAS(M^2)---------------------------RA(M^2)",
1946 LPRINT"----------TNW---DW---EXPW";
1947 LPRINT TAB(113);"RWA(M^2)";TAB(122);"TWA(M^2)":LPRINT
1948 LPRINT"                        SUMMER----------WINTER-----------";
1949 LPRINT"E------------W------------N------------S":LPRINT
1950 FOR L=1 TO X
1951 LPRINT TAB(8);C(L,1);TAB(20);ETR(L);TAB(32);ETRW(L),TAB(55);EWA(L);
1952 LPRINT TAB(65);WWA(L);TAB(75),NWA(L);TAB(85),SWA(L),TAB(92),RA(L),
1953 LPRINT TAB(99);TNW(L),TAB(106);BW(L);TAB(111),EXPW(L),TAB(118),RWA(L)
1954 NEXT L
1955 LPRINT TAB(125);TWA
1956 LPRINT
1957 LPRINT
1958 LPRINT"TOTAL ENERGY TRANSMITTED TO THE HOUSE IN (KJ/DAY)"
1959 LPRINT"SUMMER-----------------------------------WINTER"
1960 LPRINT
1962 LPRINT ETH;TAB(40);ETHW
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1964 IF T=1 THEN 1984
1965 FOR K=1 TO T
1966 PRINT "INPUT TOEXWM M=1,RB=2,S=3,RBWCN=4,SWCN=5,CN=6,LSWCN=7,RICN=8"
1967 INPUT A(K)
1968 IF A(K)<=3 THEN PRINT "INPUT GIP P=1":INPUT P
1969 IF A(K)=1 THEN UW1=2.58:GO TO 1973
1970 IF A(K)=2 THEN UW1=4.66:GO TO 1973
1971 IF A(K)=3 THEN UW1=5.29:GO TO 1973
1972 IF A(K)>3 THEN 1975
1973 GWEL(K)=(24*16.5)*((TSA-TWA)/T)*(UW1):TGWEL=TGWEL+GWEL(K)
1974 IF A(K)<=3 THEN 1983
1975 IF A(K)=4 THEN UW2=10.352:GO TO 1980
1976 IF A(K)=5 THEN UW2=10.533:GO TO 1980
1977 IF A(K)=6 THEN UW2=12.1:GO TO 1980
1978 IF A(K)=7 THEN UW2=18.678:GO TO 1980
1979 IF A(K)=8 THEN UW2=19.240:GO TO 1980
1980 CWEL(K)=(24*16.5)*((TSA-TWA)/T)*UW2
1981 TCWEL=TCWEL+CWEL(K)
1982 PRINT "INPUT CIP P=2":INPUT P
1983 UW1=0:UW2=0:NEXT K
1984 IF T>1 THEN 1999
1985 PRINT"INPUT WALL INSIDE PLASTER P=1 FOR GYPSUM,P=2 FOR CEMENT"
1986 INPUT P
1987 PRINT "INPUT TOEWM M=1,RB=2,S=3,RBWCN=4,SWCN=5,CN=6,LSWCN=7,RICN=8"
1988 INPUT W
1989 IF W=1 THEN GW=2.58:GO TO 1997
1990 IF W=2 THEN GW=4.66:GO TO 1997
1991 IF W=3 THEN GW=5.29:GO TO 1997
1992 IF W=4 THEN CW=10.352:GO TO 1997
1993 IF W=5 THEN CW=10.533:GO TO 1997
1994 IF W=6 THEN CW=12.1:GO TO 1997
1995 IF W=7 THEN CW=18.678:GO TO 1997
1996 IF W=8 THEN CW=19.240:GO TO 1997
1997 IF W>3 THEN CL=(24*16.5)*(TSA-TWA)*CW:GO TO 1999
1998 GL=(24*16.5)*(TSA-TWA)*GW
1999 IF P=1 THEN UR1=8.144:UR=7.895:GO TO 2010
2000 IF P=2 THEN UR2=8.3:UR3=37.2:UR=7.895:GO TO 2010
2010 FOR L=1 TO X
2020 IF P=2 THEN 2080
2030 GREL(L)=(24*16.5)*(UR1)*(RA(L))
2040 NREL(L)=(24*16.5)*(UR)*(RA(L))
2050 TGREL=TGREL+GREL(L)
2060 TNREL=TNREL+NREL(L)
2070 IF P=1 THEN 2140
2080 CREL1(L)=(24*16.5)*(UR2)*(RA(L))
2090 CREL2(L)=(24*16.5)*(UR2)*(RA(L))
2100 NREL(L)=(24*16.5)*(UR)*(RA(L))
2110 TCREL1=TCREL1+CREL1(L)
2120 TCREL2=TCREL2+CREL2(L)
2130 TNREL=TNREL+NREL(L)
2140 EWEL(L)=(24*16.5*3.78)*(EWA(L))
2150 WWEL(L)=(24*16.5*3.78)*(WWA(L))
2160 NWEL(L)=(24*16.5*3.78)*(NWA(L))
2170 SWEL(L)=(24*16.5*3.78)*(SWA(L))
2180 TEWEL=TEWEL+EWEL(L)
2190 TWWEL=TWWEL+WWEL(L)
2200 TNWEL=TNWEL+NWEL(L)
2210 TSWEL=TSWEL+SWEL(L)
2220 NEXT L
2230 WEL=TEWEL+TWWEL+TNWEL+TSWEL:WEL1=(61.5*24)*(TWA)
2240 IF P=1 THEN GHEL=TGWEL+((WEL+WEL1)/2)+TGREL
2250 IF P=1 THEN GNHEL=TGWEL+((WEL+WEL1)/2)+TNREL:GO TO 2290
2260 CHEL1=TCWEL+((WEL+WEL1)/2)+TCREL1
2270 CHEL2=TCWEL+((WEL+WEL1)/2)+TCREL2
2280 CNHEL=TCWEL+((WEL+WEL1)/2)+TNREL
2290 LET B(1)=GHEL:B(2)=GNHEL:B(3)=CHEL1:B(4)=CHEL2:B(5)=CNHEL
2300 FOR Y= 1 TO 5
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2310 IF B(Y)=0 THEN 2500
2320 PDPS(Y)=(ETH/B(Y))*(10^2)
2330 PDPW(Y)=(ETHW/B(Y))*(10^2)
2340 BLC(Y)=(1/16.5)*B(Y)
2350 MTLS(Y)=(22)*(BLC(Y))
2360 MTLW(Y)=(90)*(BLC(Y))
2370 SLRS(Y)=(31)*(ETH/MTLS(Y))
2380 SLRW(Y)=(31)*(ETHW/MTLW(Y))
2390 IF SLRS(Y)<0.1 THEN SHFS(Y)=(0.6182)*(SLRS(Y)):GO TO 2410
2400 SHFS(Y)=((1.0097)-(1.0710)*(EXP(-1.2208*SLRS(Y))))
2410 IF SLRW(Y)<0.1 THEN SHFW(Y)=(0.6182)*(SLRW(Y)):GO TO 2430
2420 SHFW(Y)=((1.0097)-(1.0710)*(EXP(-1.2208*SLRW(Y))))
2430 IF SHFS(Y)>1 THEN AUXS(Y)=0:GO TO 2432
2431 AUXS(Y)=(1-SHFS(Y))*(BLC(Y)*22)
2432 IF SHFW(Y)>1 THEN AUXW(Y)=0:GO TO 2450
2440 AUXW(Y)=(1-SHFW(Y))*(BLC(Y)*90)
2450 CS(Y)=(2.8*(10^-4)*0.75)*(AUXS(Y))
2460 CW(Y)=(2.8*(10^-4)*0.75)*(AUXW(Y))
2470 AAUXS(Y)=(8)*(AUXS(Y)):AAUXW(Y)=(4)*(AUXW(Y))
2480 ACS(Y)=(8)*(CS(Y)):ACW(Y)=(4)*(CW(Y))
2490 EWLCR(Y)=(BLC(Y)/ESA):NSLCR(Y)=(BLC(Y)/SSA)
2500 NEXT Y
2510 LPRINT
2520 LPRINT"HOUSE ENERGY LOSS AND ITS DISTRIBUTION  IN (KJ/DAY)"
2530 LPRINT"LOSS VIA WALLS-------SN--PLASTER--WT--ENERGY LOSS IN(KJ/DAY)",
2540 LPRINT"-----------------              TOTAL          "
2550 LPRINT"                                                  GPW           CPW    ",
2560 LPRINT TAB(70);"GPW";TAB(90);"CPW"
2565 LPRINT
2570 IF T=1 THEN 2620
2580 FOR K=1 TO T
2590 LPRINT TAB(20);T;TAB(26);P;TAB(34);A(K);TAB(38);GWEL(K);TAB(50);CWEL
2600 NEXT K
2610 IF T>1 THEN 2630
2620 LPRINT TAB(20);T;TAB(26);P;TAB(34);W;TAB(38);GL;TAB(50);CL:GO TO 2650
2630 LPRINT
2640 LPRINT TAB(70);TGWEL;TAB(90);TCWEL
2650 LPRINT
2660 LPRINT"LOSS VIA ROOFS---------------P------------ENERGY LOSS IN(KJ/DAY)",
2670 LPRINT"---------------               TOTAL          "
2680 LPRINT"                                   GPR----------NPR----------CPR1--------
2690 LPRINT TAB(75);"GPR";TAB(85);"NPR";TAB(95);"CPR1";TAB(105);"CPR2"
2700 LPRINT
2710 FOR L=1 TO X
2720 LPRINT TAB(26);P;TAB(29);GREL(L);TAB(39);NREL(L);TAB(50);
2730 LPRINT CREL1(L);TAB(63);CREL2(L);
2740 NEXT L
2750 LPRINT
2760 LPRINT TAB(75);TGREL;TAB(85);TNREL;TAB(95);TCREL1;TAB(105);TCREL2
2770 LPRINT
2780 LPRINT"LOSS VIA WINDS -----------ENERGY LOSS IN(KJ/DAY)";
2790 LPRINT"-------------TOTAL                      "
2800 LPRINT"                          E-----------W------------N-----------S.";
2810 LPRINT"----------------E--------W--------N--------S          WEL    WEL1"
2820 LPRINT
2830 FOR L=1 TO X
2840 LPRINT TAB(20);EWEL(L);TAB(30);WWEL(L);TAB(40);NWEL(L);
2850 LPRINT TAB(50);SWEL(L);
2860 NEXT L
2870 LPRINT
2880 LPRINT TAB(70);TEWEL;TAB(80);TWWEL;TAB(90);TNWEL;TAB(100);TSWEL;
2890 LPRINT WEL;TAB(120);WEL1
2900 LPRINT
2910 LPRINT "DISTRIBUTION OF THE TOTAL HOUSE HEAT LOSS IN (KJ/DAY)" 
2920 LPRINT
2930 LPRINT"    VIA WALLS                      VIA WINDS --------------------",
2935 LPRINT"---------VIA ROOFS                    "
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2940 LPRINT
2950 LPRINT"GP--------------CP-------------E---------------W-----------------N----------------";
2955 LPRINT"S------------GP------NP------------CP1-----------CP2----------"
2960 LPRINT
2970 IF T=1 THEN LPRINT GL;TAB(13);CL: GO TO 2985
2980 LPRINT TGWEL;TAB(13);TCWEL;
2985 LPRINT TAB(23);TEWEL;TAB(33);TWWEL;TAB(43),TNWEL;
2990 LPRINT TAB(55);TSWEL;TAB(65),TGREL;TAB(75);TNREL,TAB(91);TCREL1;
3000 LPRINT TAB(104);TCREL2
3010 LPRINT
3020 LPRINT "                    OVER ALL HOUSE HEAT LOSS
3030 LPRINT
3040 LPRINT"HT---------OVERALL HOUSE HEAT LOSS IN (KJ/DAY)
3050 LPRINT
3060 FOR Y=1 TO 5
3070 LPRINT Y,B(Y)
3080 NEXT Y
3090 LPRINT
3100 LPRINT "                     HOUSE QUALITY FACTORES
3105 LPRINT
3110 LPRINT"HT              PDPS             PDPW          BLC(KJ/DD)";
3115 LPRINT"       MTLS            MTLW"
3120 LPRINT
3140 FOR Y=1 TO 5
3150 LPRINT Y,PDPS(Y),PDPW(Y),BLC(Y),MTLS(Y),MTLW(Y)
3170 NEXT Y
3180 LPRINT
3190 LPRINT"HT               SLRS              SLRW          SHFS
3195 LPRINT"SHFW           AUXS          AUXW"
3210 LPRINT
3230 FOR Y=1 TO 5
3240 LPRINT Y,SLRS(Y),SLRW(Y),SHFS(Y),SHFW(Y),AUXS(Y),AUXW(Y)
3260 NEXT Y
3270 LPRINT
3280 LPRINT"HT              MCS(R)            MCW(R)---------";
3285 LPRINT"AAUS(KJ)       AAUXW(KJ)"
3300 LPRINT
3310 FOR Y=1 TO 5
3320 LPRINT Y,CS(Y),CW(Y),AAUXS(Y),AAUXW(Y)
3330 NEXT Y
3331 LPRINT
3332 LPRINT"HT              ACS(R)            ACW(R)";
3333 LPRINT"---------ELCR(KJ/DDM^2)        SLCR(KJ/M^2DD)"
3334 FOR Y=1 TO 5
3335 LPRINT Y,ACS(Y),ACW(Y),EWLCR(Y),NSLCR(Y)
3336 NEXT Y
3340 K1=0: H1=0: Z=0: ESA=0: WSA=0: NSA=0: SSA=0: TSA=0
3350 ESE=0: WSE=0: NSE=0: SSE=0: ESEW=0: WSEW=0: NSEW=0: SSEW=0: EFHS=0: EFHW=0
3360 ETH=0: ETHW=0: TWA=0: TEWEL=0: TWWEL=0: TSWEL=0: TNWEL=0: WEL=0: WEL1=0
3370 CHEL1=0: CHEL2=0: GHEL=0: GNHEL=0: CNHEL=0: GL=0: CL=0: TGREL=0: TNREL=0
3380 TCREL1=0: TCREL2=0: W=0: P=0
3390 FOR K=1 TO T: A(K)=0: GWEL(K)=0: CWEL(K)=0: NEXT K: T=0
3400 FOR L=1 TO X
3410 FOR M=1 TO 17
3420 C(L,M)=0: NEXT M
3430 RA(L)=0: TNW(L)=0: EW(L)=0: EXPW(L)=0: EWA(L)=0: WWA(L)=0: NWA(L)=0
3440 SWA(L)=0: WE1(L)=0: WE2(L)=0: WE3(L)=0: WE4(L)=0
3450 WEW1(L)=0: WEW2(L)=0: WEW3(L)=0: WEW4(L)=0
3460 ETR(L)=0: ETRW(L)=0: RWA(L)=0: GREL(L)=0: NREL(L)=0: CREL1(L)=0: CREL2(L)=0
3470 EWEL(L)=0: WWEL(L)=0: NWEL(L)=0: SWEL(L)=0
3480 NEXT L
3490 FOR Y=1 TO 5
3500 B(Y)=0
3510 PDPS(Y)=0: PDPW(Y)=0: SLRS(Y)=0: SLRW(Y)=0: SHFS(Y)=0: SHFW(Y)=0
3520 AUXS(Y)=0: AUXW(Y)=0: CS(Y)=0: CW(Y)=0: AAUXS(Y)=0: AAUXW(Y)=0
3530 ACS(Y)=0: ACW(Y)=0: EWLCR(Y)=0: NSLCR(Y)=0
```

```
3540 NEXT Y: X=0: T=0: W=0: P=0
3550 NEXT J
3560 END
```

```
10 DIM B$(40),F%(10,35),D(13,3),WH(13),DH(13),M%(4,3),W(6)
20 DIM C(7),G(5),ADCE(20),AWCE(20)
25 PRINT CHR$(27)+"*"
26 INPUT"ENTER FI";N$
27 OPEN "I",#1,N$
30 FOR I=1 TO 35
40 INPUT #1,B$(I)
50 NEXT I
73 FOR J=1 TO 10
80 FOR I=1 TO 35
90 PRINT " INPUT TYPE OF FUEL AND THE USE OF ENERGY RESOURCES"
100 INPUT F%(J,I)
110 NEXT I
120 IF F%(J,1)>0 THEN GOSUB 500
130 IF F%(J,2)>0 THEN GOSUB 1000
140 IF F%(J,3)>0 THEN GOSUB 1500
150 IF F%(J,4)>0 THEN GOSUB 2000
160 LPRINT
165 LPRINT TAB(30);"FI=";J
166 LPRINT
167 LPRINT TAB(30);"TYPE OF ENERGY RESOURCES USED IN YEMENI BUILDINGS"
168 LPRINT
169 FOR I=1 TO 7
170 LPRINT B$(I),F%(J,I)
171 NEXT I
172 LPRINT
173 LPRINT TAB(30);"USE OF ENERGY RESOURCES"
174 LPRINT
175 LPRINT TAB(30);"ELECTRICITY USE"
176 LPRINT
177 FOR I=8 TO 17
178 LPRINT B$(I),F%(J,I)
179 NEXT I
180 LPRINT
181 LPRINT TAB(30);"WOOD USE"
182 LPRINT
183 FOR I=18 TO 23
184 LPRINT B$(I),F%(J,I)
185 NEXT I
186 LPRINT
187 LPRINT TAB(30);"CHARCOAL USE"
188 LPRINT
189 FOR I=24 TO 30
190 LPRINT B$(I),F%(J,I)
191 NEXT I
192 LPRINT
193 LPRINT TAB(30);"KERISONE USE"
194 LPRINT
195 FOR I=31 TO 35
196 LPRINT B$(I),F%(J,I)
197 NEXT I
198 LPRINT
221 FOR K=1 TO 13
222 FOR L=1 TO 3
223 D(K,L)=0
224 NEXT L
225 DH(K)=0
226 ADCE(K)=0
227 AWCE(K)=0
228 NEXT K
229 FOR M=1 TO 4
230 FOR N=1 TO 3
231 M%(M,N)=0
232 NEXT N
233 NEXT M
234 HCEW=0
235 HCES=0
236 HCER=0
```

```
237 AHCE=0
238 ACEL=0
239 ACCC=0
240 ACED=0
241 ACCCOL=0
242 ACEH=0
243 ECHS=0
244 ECHW=0
245 AMHS=0
246 AMHW=0
247 Z=0
248 HCWW=0
249 HCWS=0
250 YCNW=0
251 YCNS=0
252 WEW=0
253 WES=0
254 AMSW=0
255 AMSS=0
256 FOR Y=1 TO 6
257 W(Y)=0
258 NEXT Y
259 FOR X=1 TO 7
260 C(X)=0
261 NEXT X
262 DUG=0
263 WUG=0
264 DCG=0
265 HCG=0
266 FOR R=1 TO 5
267 G(R)=0
268 NEXT R
269 FOR I=1 TO 35
270 F%(J,I)=0
271 NEXT I
280 NEXT J
285 CHAIN "MUT"
500 LPRINT
560 LPRINT
570 FOR K=1 TO 13
580 FOR L=1 TO 3
590 PRINT "INPUT EQ.USE AND TIME IN MINUTES"
600 INPUT D(K,L)
610 NEXT L
615 PRINT K
620 NEXT K
621 FOR K=1 TO 13
622 DH(K)=(D(K,3)/60)*(D(K,1)+(1/7)*(D(K,2)))
624 NEXT K
625 LPRINT TAB(30);"EQUIPMENTS USED IN THE HOUSE AND THIER USE IN (HR/DA
626 LPRINT
627 FOR K=1 TO 13
628 LPRINT K,DH(K)
629 NEXT K
630 FOR M=1 TO 4
640 FOR N=1 TO 3
650 PRINT "INPUT AMOUNT OF MONEY SPENT ON FUEL IN FORM OF 3X4 MATRIX"
655 INPUT M%(M,N)
660 NEXT N
670 NEXT M
671 LPRINT
672 LPRINT"AMOUNT OF MONEY SPENT ON FUEL IN (RAIL/MONTH)"
673 LPRINT
674 LPRINT"----------WINTER----------SUMMER------RAMADAN"
675 LPRINT
```

```
676 FOR M=1 TO 4
677 LPRINT TAB(6);M%(M,1);TAB(21);M%(M,2);TAB(31);M%(M,3)
678 NEXT M
679 LPRINT
680 PRINT "INPUT THE FAMILY LOCATION CITY=10,VILAGE=1"
690 INPUT X
700 IF X=1 THEN DCEW=(M%(2,1))/(30):GO TO 715
710 DCEW=(M%(2,1))/(30*0.75)
715 IF X=1 THEN DCES=(M%(2,2))/(30):GO TO 725
720 DCES=(M%(2,2))/(30*0.75)
725 IF X=1 THEN DCER=(M%(2,3))/(30):GO TO 735
730 DCER=(M%(2,3))/(30)
735 ADCE=(DCEW+DCES+DCER)/(3)
736 IF F%(J,8)=0 THEN ACEL=0:GO TO 745
740 ACEL=ADCE*(7/24)
745 IF F%(J,9)=0 THEN ACEC=0:GO TO 770
750 ACEC=ADCE*(4/24)
770 IF F%(J,14)=0 THEN ACED=0:GO TO 781
780 ACED=ADCE*(0.30/24)
781 IF F%(J,15)=0 THEN ACECOL=0:GO TO 782
782 IF F%(J,16)=0 THEN ACEH=0:GO TO 790
783 ACECOL=ADCE*(6/24)
784 ACEH=ADCE*(6/24)
785 ECHS=(3.6/156)*(ACEH)
786 AMHS=(156*12*0.75/3.6)*(ECHS)
787 ECHW=(3.6/190)*(ACEH)
788 AMHW=(190*12*0.75/3.6)*(ECHW)
790 LPRINT "DAILY CONSUMPTION OF ELECTRICITY IN KWHR/DAY"
800 LPRINT
810 LPRINT "----------WINTER       SUMMER    RAMADAN        AVG"
811 LPRINT
812 LPRINT TAB(8);DCEW;TAB(21);DCES;TAB(31);DCER;TAB(45),ADCE
813 LPRINT
820 FOR K=4 TO 13
830 ADCE(K)=DH(K)*(ADCE/24)
840 AWCE(K)=WH(K)*(ADCE/24)
850 NEXT K
860 LPRINT "DISTRIBUTION OF ELECTRICITY IN KWHR/DAY"
870 LPRINT
880 LPRINT "LI------------CO-------------WD------------HC------------HH"
890 LPRINT
895 LPRINT ACEL;TAB(12);ACEC;TAB(24);ACED;TAB(35);ACECOL,TAB(47);ACEH
896 LPRINT:LPRINT
897 LPRINT "TOE-----------------DAILY CONS.----WEEKLY CONS."
900 FOR K=4 TO 13
910 LPRINT K,ADCE(K),AWCE(K)
920 NEXT K
925 LPRINT
930 LPRINT" ENERGY EQUIVALENT FOR HEATING IN (MJ/DD)"
935 LPRINT
940 LPRINT"----------WINTER-------SUMMER"
945 LPRINT
950 LPRINT TAB(8);ECHW;TAB(21);ECHS
951 LPRINT
955 LPRINT "COST OF ENERGY EQIVALENT IN RAIL"
956 LPRINT "----------WINTER-------SUMMER"
957 LPRINT
958 LPRINT TAB(8);AMHW;TAB(21);AMHS
959 LPRINT
960 RETURN
1000 LET Z=DH(1)
1001 IF Z=0 THEN 1051
1040 HCWW=(M%(1,1)*0.5)/(30*Z)
1050 HCWS=(M%(1,2)*0.5)/(30*Z)
1051 YCNW=(1.5165*12*10^-4)*(M%(1,1))
1052 YCNS=(1.5165*12*10^-4)*(M%(1,2))
```

```
1053 WEW=(3.8561)*(YCNW)
1054 WES=(4.697)*(YCNS)
1055 AMSW=(1710)*(WEW)
1056 AMSS=(1404)*(WES)
1060 LPRINT
1110 LPRINT "WOOD INFORMATION"
1140 LPRINT
1141 LPRINT"                                      WINTER           SUMMER"
1142 LPRINT
1150 LPRINT "CONSUMPTION(KG/HR)";TAB(32);HCWW;TAB(48);HCWS
1180 LPRINT
1190 LPRINT "COST(RAIL/MON)";TAB(32);M%(1,1)/30;TAB(48);M%(1,2)/30
1191 LPRINT
1194 LPRINT "YEARLY NO. OF CORDS";TAB(32);YCNW;TAB(48);YCNS
1197 LPRINT
1198 LPRINT "ENERGY EQIV. (KWHR/DD)";TAB(32);WEW;TAB(48);WES
1199 LPRINT
1201 LPRINT
1202 LPRINT "COST(RAIL/YEAR)";TAB(32);AMSW;TAB(48);AMSS
1205 LPRINT
1206 LPRINT "WOOD CONS(M^3/YEAR)";TAB(32);(3.625*YCNW)
1207 LPRINT:LPRINT
1208 IF F%(J,5)=0 THEN 1360
1360 RETURN
1500 LPRINT TAB(30);"GAS INFORMATION"
1510 LPRINT
1520 LPRINT TAB(32);"WINTER ------------SUMMER"
1535 LPRINT
1536 LPRINT "COST(RAIL/MON)";TAB(32);M%(3,1);TAB(48);M%(3,2)
1540 DUG=DH(2)+DH(3)
1550 WUG=WH(2)+WH(3)
1560 IF DUG=0 THEN 1580
1570 DCG=(M%(3,1)+M%(3,2))/(60*0.83)
1575 HCG=DCG/DUG
1580 LPRINT
1596 LPRINT "DAILY USE OF GAS(HR)";TAB(40);DUG
1597 LPRINT
1610 LPRINT "GAS CONS. (L/HR)";TAB(40);HCG
1640 RETURN
2000 LPRINT:LPRINT
2045 LPRINT "KERISONE INFORMATION"
2060 LPRINT
2070 LPRINT "COST(RAIL/MON)";TAB(32);M%(4,1);TAB(48);M%(4,2)
2200 RETURN
```

```
10 DIM W$(17),C%(7,3),W%(10,40),HWD(7),H(10),V(10),A%(10,24)
15 DIM B%(10,24),HR(10),VR(10),NA%(10,24),NB%(10,24)
20 INPUT"ENTER W1,HWD RESPECTIVELY";N$
25 OPEN "I",#1,N$
26 IF N$="HWD" THEN 60
30 FOR I=1 TO 17
35 INPUT #1,W$(I)
36 NEXT I
37 PRINT
38 CLOSE #1
39 GO TO 20
60 FOR L=1 TO 7
70 FOR M=1 TO 3
80 INPUT #1,C%(L,M)
100 NEXT M
110 NEXT L
120 FOR J=1 TO 10
130 FOR K=1 TO 40
140 PRINT "INPUT Q17-Q22"
150 INPUT W%(J,K)
160 NEXT K
170 W1=W%(J,1)*(2^3)+W%(J,2)*(2^2)+W%(J,3)*(2^1)+W%(J,4)*(2^0)
180 TI=W%(J,1)*(2^1)+W%(J,2)*(2^0)
190 PI=W%(J,3)*(2^1)+W%(J,4)*(2^0)
240 DCWW=W%(J,5)/30
245 MSWW=W%(J,6)/30
300 DCWS=W%(J,7)/30
310 MSWS=W%(J,8)/30
315 L=1:I=1
320 FOR K=21 TO 27
330 IF C%(L,3)=0 THEN HWD(I)=(W%(J,K)*C%(L,1)*C%(L,2)):GO TO 350
340 HWD(I)=(W%(J,K)*C%(L,1)*C%(L,3))/(7)
350 THWD=THWD+HWD(I)
360 L=L+1:I=I+1
370 NEXT K
380 PHW=(THWD/DCWW)
390 PHS=(THWD/DCWS)
395 N=1
400 FOR K=31 TO 40
410 PRINT "INPUT SOLAR ENERGY RANKING HOUSE,VILAAGE"
420 INPUT H(N),V(N)
430 HR(N)=W%(J,K)*H(N)
440 VR(N)=W%(J,K)*V(N)
450 N=N+1
460 NEXT K
470 FOR Y=1 TO 3
480 IF Y=1 THEN CWD1=(0.1)*(DCWW):GO TO 510
490 IF Y=2 THEN CWD2=(0.033)*(DCWW):GO TO 510
500 CWD3=(0.06)*(DCWW)
510 NEXT Y
535 TCWD=(CWD1*3)+(CWD2*8)+(CWD3*8)
540 FOR Y=1 TO 3
550 IF Y=1 THEN CWDS1=(0.1)*(DCWS):GO TO 570
560 IF Y=2 THEN CWDS2=(0.03)*(DCWS):GO TO 570
565 CWDS3=(0.06)*(DCWS)
570 NEXT Y
580 TCWDS=(3*CWDS1+8*CWDS2+8*CWDS3)
590 FRW=(TCWD/19)
600 FRS=(TCWDS/19)
605 LPRINT "                    FAMILY INDEX=                  ";J
606 LPRINT
610 LPRINT "W1                  T1                 P1"
611 LPRINT
612 LPRINT W1;TAB(18);T1;TAB(34);P1
613 LPRINT
620 LPRINT "DCWW(L/DAY)------DCWS(L/DAY)--------MSWW(RAIL)--------MSWS(RAIL)"
630 LPRINT
```

```
640 LPRINT DCWW; TAB(18); DCWS; TAB(34); MSWW; TAB(54); MSWS
650 LPRINT
655 LPRINT TAB(30); "COLD WATER DISTRIBUTION IN (L/HR)"
660 LPRINT
670 LPRINT "6-8------9-17------17-24---------TCWD(L/DAY)-----FRW(L/HR)----FRS
675 LPRINT
680 LPRINT CWD1; TAB(9); CWD2; TAB(19); CWD3; TAB(30); TCWD; TAB(45); FRW
685 LPRINT
690 LPRINT CWDS1; TAB(9); CWDS2; TAB(19); CWDS3; TAB(30); TCWDS; TAB(58); FRS
695 LPRINT
830 FOR I=1 TO 7
840 LPRINT TAB((I-1)*10+4); W$(I);
850 NEXT I
860 LPRINT
870 FOR I=1 TO 7
880 LPRINT TAB((I-1)*10+4); HWD(I);
890 NEXT I
900 LPRINT: LPRINT
910 LPRINT "THWD-(L/DAY)-----------------PHW----------------------------PHS"
920 LPRINT
930 LPRINT THWD; TAB(24); PHW; TAB(45); PHS
940 LPRINT: LPRINT
950 LPRINT "RANKING OF SOLAR ENERGY APPLICATIONS"
960 LPRINT
970 FOR I=8 TO 17
980 LPRINT TAB((I-8)*5+4); W$(I);
990 NEXT I
1000 LPRINT
1010 FOR N=1 TO 10
1020 LPRINT TAB((N-1)*5+4); HR(N);
1030 NEXT N
1040 LPRINT
1050 FOR N=1 TO 10
1060 LPRINT TAB((N-1)*5+4); VR(N),
1070 NEXT N
1071 LPRINT
1072 PRINT "INPUT THE FAMILY LOCATION C=10, V=1)"
1073 INPUT X
1080 IF PI=0 THEN IF X=10 THEN GOSUB 2000
1090 IF PI>0 THEN IF X=10 THEN GOSUB 5000
1091 IF PI=0 THEN IF X=1 THEN GOSUB 7000
1092 IF PI>0 THEN IF X=1 THEN GOSUB 9000
1093 DCWW=0: DCWS=0: MSWW=0: MSWS=0: CWD1=0: CWD2=0: CWD3=0: TCWD=0: FRW=0: FRS=0
1094 FOR I=1 TO 7: HWD(I)=0: NEXT I: THWD=0: PHW=0: PHS=0: X=0: TI=0: WI=0: PI=0
1095 FOR N=1 TO 10: HR(N)=0: VR(N)=0: NEXT N: RC1=0: RC2=0: RC3=0: TRC=0: RFR=0
1096 TA=0: GC1=0: GC2=0: GC3=0: TGC=0: GFR=0: ADCW=0: ADCS=0: NADCW=0: NADCS=0
1097 AFRW=0: AFRS=0: FEW=0: FES=0: QW=0: QS=0: EFW=0: EFS=0: LF=0: ENHW=0: ENHS=0
1098 LEW=0: LES=0: HAUXW=0: HAUXS=0: TLW=0: TLS=0: MSTLW=0: MSTLS=0: Z=0: TPC=0
1099 TPD=0: PGC=0: TPGD=0: PD1=0: PD2=0: PD3=0: PGD1=0: PGD2=0: PGD3=0: RPFR=0
1100 GPFR=0: PCF=0: PCP=0: M=0: PC1=0: PC2=0: PC3=0: TPC=0
1110 NEXT J
2000 PRINT "PRESSURIZED SYSTEM"
2001 LPRINT
2040 IF WI=12 THEN LPRINT "PRESSURIZED SYSTEM WITH RHS TANK": GO TO 2080
2050 IF WI=8 THEN LPRINT "PREESURIZED SYSTEM WITH R-STORAGE TANK": GO TO 2[illegible]
2060 IF WI=4 THEN LPRINT "PRESSURIZED SYSTEM H-STORAGE TANK": GO TO 2230
2070 IF WI=0 THEN LPRINT "PRESSURIZED SYSTEM WITH NO STORAGE": GO TO 3100
2080 IF W%(J,9)=0 THEN 2100
2090 DRC1=W%(J,9)*W%(J,11)
2091 WRC1=W%(J,9)*W%(J,12)
2100 IF W%(J,13)=0 THEN 2120
2110 DRC2=W%(J,13)*W%(J,15)
2111 WRC2=W%(J,13)*W%(J,16)
2120 IF W%(J,17)=0 THEN 2140
2130 DRC3=W%(J,17)*W%(J,19)
2131 WRC3=W%(J,17)*W%(J,20)
```

```
2140 TDRC=DRC1+DRC2+DRC3
2145 TWRC=WRC1+WRC2+WRC3
2146 GRC=TDRC+TWRC/7
2160 FOR Y=1 TO 3
2170 IF Y=1 THEN RC1=(0.1)*(GRC):GO TO 2200
2180 IF Y=2 THEN RC2=(0.033)*(GRC):GO TO 2200
2190 RC3=(0.06)*(GRC)
2200 NEXT Y
2210 TRC=(RC1*3)+(RC2*8)+(RC3*8)
2220 RFR=(TRC/19)
2225 IF WI=8 THEN 2334
2230 IF W%(J,29)=0 THEN 2250
2240 GDC=(W%(J,28)/W%(J,29))
2250 IF W%(J,30)=0 THEN 2270
2260 GDC=(W%(J,28)/(W%(J,30)*7))
2270 FOR Y=1 TO 3
2280 IF Y=1 THEN GC1=(0.1)*(GDC):GO TO 2310
2290 IF Y=2 THEN GC2=(0.03)*(GDC):GO TO 2310
2300 GC3=(0.06)*(GDC)
2310 NEXT Y
2320 TGC=(GC1*3)+(GC2*8)+(GC3*8)
2330 GFR=(TGC/19)
2334 IF WI=4 THEN 2650
2337 TA=(10^-3)*(W%(J,9)+W%(J,13)+W%(J,17))
2340 SW=(7.95*10^-2)*(RFR)
2350 QS=(12.14*10^-2)*(RFR)
2360 EFW=(0.099662)*(RFR/TA)
2370 EFS=(0.122737)*(RFR/TA)
2380 LF=(1212)*(EFW-EFS)
2400 ENHW=(0.00247)*(THWD)
2410 ENHS=(0.00377)*(THWD)
2420 LEW=(10)*(ABS(LF)*TA)
2430 LES=(20)*(ABS(LF)*TA)
2440 HAUXW=(0.00268)*(LEW)
2450 HAUXS=(0.00268)*(LES)
2460 TLW=HAUXW+ENHW
2470 TLS=HAUXS+ENHS
2471 MSTLW=(208.33)*(TLW)
2472 MSTLS=(208.33)*(TLS)
2475 IF WI=8 THEN 2560
2480 ADCW=(TCWD+TRC+TGC)/(3)
2490 ADCS=(TCWDS+TRC+TGC)/(3)
2500 AFRW=(FRW+RFR+GFR)/(3)
2510 AFRS=(FRS+RFR+GFR)/(3)
2520 NADCW=(AFRW)*(19)
2530 NADCS=(AFRS)*(19)
2540 PEW=(NADCW-ADCW)/(DCWW)
2550 PES=(NADCS-ADCS)/(DCWS)
2553 IF WI=12 THEN 2760
2560 ADCW=(TCWD+TRC)/(2)
2570 ADCS=(TCWDS+TRC)/(2)
2580 AFRW=(FRW+RFR)/(2)
2590 AFRS=(FRS+RFR)/(2)
2600 NADCW=(AFRW)*(19)
2610 NADCS=(AFRS)*(19)
2620 PEW=(NADCW-ADCW)/(DCWW)
2630 PES=(NADCS-ADCS)/(DCWS)
2640 IF WI=8 THEN 2760
2650 ADCW=(TCWD+TGC)/(2)
2660 ADCS=(TCWDS+TGC)/(2)
2670 AFRW=(FRW+GFR)/(2)
2680 AFRS=(FRS+GFR)/(2)
2690 NADCW=(AFRW)*(19)
2700 NADCS=(AFRS)*(19)
2710 PEW=(NADCW-ADCW)/(DCWW)
2720 PES=(NADCS-ADCS)/(DCWS)
```

```
2760 LPRINT "                    FAMILY INDEX=                   ";J
2761 LPRINT
2762 LPRINT "TI--------PI--------WI"
2780 LPRINT
2790 LPRINT TI;TAB(10);PI;TAB(19);WI
2800 LPRINT
2801 REM IF WI=4 THEN 2840
2810 LPRINT "DISRTRIBUTION OF COLD WATER CONSUMED FROM STORAGE TANKS"
2820 LPRINT
2840 LPRINT "6-8------9-16------17-24------TC(L/DAY)------FR(L/HR)-----TA(M^2)
2850 LPRINT
2855 IF WI=4 THEN 2870
2860 LPRINT RC1;TAB(10);RC2;TAB(20);RC3;TAB(28);TRC;TAB(40),RFR;TAB(50),TF
2870 LPRINT
2900 LPRINT GC1;TAB(10);GC2;TAB(20);GC3;TAB(28);TGC;TAB(40);GFR
2910 LPRINT
2920 LPRINT "AVERAGE DAILY CONSUMPTION OF COLD WATER IN WINTER---------SUM"
2930 LPRINT
2940 LPRINT TAB(45);ADCW;TAB(59);ADCS
2950 LPRINT
2960 LPRINT "CORRECTED AVERAGE DAILY CONSUMPTION OF WATER(L/DAY)---------"
2970 LPRINT
2980 LPRINT TAB(45);NADCW;TAB(59);NADCS
2990 LPRINT
2995 LPRINT "AVERAGE FLOW RATE(L/HR)----------------------------------------"
3000 LPRINT
3010 LPRINT TAB(45);AFRW;TAB(59);AFRS
3020 LPRINT
3030 LPRINT "PERCENTAGE OF ERROR---------------------------------------------
3040 LPRINT
3050 LPRINT TAB(45);ABS(PEW);TAB(59);ABS(PES)
3055 IF WI=4 THEN 3170
3060 LPRINT
3061 LPRINT "AMOUNT OF ENERGY GAINED BY TANKS(MJ/HR) IN WINTER--------SUM"
3062 LPRINT
3063 LPRINT TAB(45);QW;TAB(60);QS
3070 LPRINT "AVERAGE TANK INSTENANEOUS EFFICIENCY-IN WINTER-----------SUM"
3080 LPRINT
3090 LPRINT TAB(45);EFW;TAB(60);EFS
3091 LPRINT
3092 LPRINT "TANK U-FACTOR (W/M^2DEG) ---------------------------------------"
3093 LPRINT
3094 LPRINT TAB(22);ABS(LF)
3095 LPRINT
3096 LPRINT "ENERGY NEEDED TO HEAT WATER (GJ) IN WINTER---------------------"
3097 LPRINT
3098 LPRINT TAB(36);ENHW;TAB(60);ENHS
3099 LPRINT
3100 LPRINT "HOT WATER LOAD (W) IN WINTER---------------------------------SUM"
3110 LPRINT
3120 LPRINT TAB(24);LEW;TAB(60);LES
3130 LPRINT
3140 LPRINT "AUX ENERGY(GJ) IN WINTER-----------------------------------SUMMER"
3150 LPRINT
3160 LPRINT TAB(21);HAUXW;TAB(60);HAUXS
3161 LPRINT
3162 LPRINT "MONTHLY TOTAL LOAD (GJ) IN WINTER-------------------SUMMER"
3163 LPRINT
3164 LPRINT TAB(33);TLW;TAB(56);TLS
3165 LPRINT
3166 LPRINT "MONTHLY MONEY SPENT TO MEET THE LOAD---WINTER-------SUMMER"
3167 LPRINT TAB(40);MSTLW;TAB(55);MSTLS
3170 RETURN
5000 LPRINT TAB(30);"CITY PUMP SYSTEM"
5010 IF WI=13 THEN LPRINT "R PUMP SYSTEM WITH G. AND R. TANK" GO TO 5070
5020 IF WI=9 THEN LPRINT "ROOF PUMP SYSTEM WITH ROOF TANK ONLY" GO TO 507
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5030 IF WI=6 THEN LPRINT "HOUSE PUMP SYSTEM WITH HOUSE TANK":GO TO 5230
5040 IF WI=3 THEN LPRINT "PUMP SYSTEM WITH NO STORAGE":GO TO 6020
5050 IF WI=2 THEN LPRINT "HOME PUMP SYSTEM WITH NO STORAGE":GO TO 6020
5060 IF WI=1 THEN LPRINT "ROOF PUMP SYSTEM WITH NO STORAGE":GO TO 6020
5070 PRINT "INPUT THE NO. OF ROOF TANKS"
5080 INPUT Z
5090 IF W%(J,12)=0 THEN PC1=W%(J,9)*W%(J,11):GO TO 5105
5100 PC1=W%(J,9)*(W%(J,12)/7)
5105 IF Z=1 THEN 5150
5110 IF W%(J,16)=0 THEN PC2=W%(J,13)*W%(J,15):GO TO 5125
5120 PC2=(W%(J,17)*W%(J,16)/7)
5125 IF Z=2 THEN 5150
5130 IF W%(J,20)=0 THEN PC3=W%(J,17)*W%(J,19):GO TO 5150
5140 PC3=(W%(J,17)*W%(J,20)/7)
5150 TPC=PC1+PC2+PC3
5160 FOR Y=1 TO 3
5170 IF Y=1 THEN PD1=(0.1)*(TPC):GO TO 5200
5180 IF Y=2 THEN PD2=(0.033)*(TPC):GO TO 5200
5190 PD3=(0.06)*(TPC)
5200 NEXT Y
5210 TPD=(PD1*3+PD2*8+PD3*8)
5220 RPFR=(TPD/19)
5225 IF WI=9 THEN 5334
5230 IF W%(J,30)=0 THEN PGC=(W%(J,28)/W%(J,29)):GO TO 5250
5240 PGC=(W%(J,28)/(W%(J,30)*7))
5250 FOR Y=1 TO 3
5260 IF Y=1 THEN PGD1=(0.1)*(PGC):GO TO 5290
5270 IF Y=2 THEN PGD2=(0.033)*(PGC):GO TO 5290
5280 PGD3=(0.06)*(PGC)
5290 NEXT Y
5300 TGPD=(PGD1*3+PGD2*8+PGD3*8)
5330 GPFR=(TGPD/19)
5334 IF WI=6 THEN 5650
5335 NPT1=(0.00125)*(W%(J,11)+W%(J,15)+W%(J,19))
5336 NPT2=(0.00125*0.14286)*(W%(J,12)+W%(J,16)+W%(J,20))
5337 NPT=NPT1+NPT2
5338 TA=(10^-3)*(W%(J,9)+W%(J,13)+W%(J,17))
5340 QW=(7.95*10^-2)*(RPFR)
5350 QS=(12.14*10^-2)*(RPFR)
5360 EFW=(0.099662)*(RPFR/TA)
5370 EFS=(0.122737)*(RPFR/TA)
5380 LF=(1212)*(EFW-EFS)
5390 PCF=(27.890)*(RPFR/(TA*ABS(LF)))
5400 ENHW=(0.00247)*(THWD)
5410 ENHS=(0.00377)*(THWD)
5420 LEW=(10)*(TA*ABS(LF))
5430 LES=(20)*(TA*ABS(LF))
5440 HAUCW=(0.00268)*(LEW)
5450 HAUXS=(0.00377)*(LES)
5451 PCP=(0.35*0.7457)*(PCF*NPT)
5452 M=(0.75*31)*(PCP)
5460 TLW=HAUXW+ENHW
5470 TLS=HAUXS+ENHS
5471 IF WI=9 THEN 5560
5480 ADCW=(TCWD+TPD+TGPD)/(3)
5490 ADCS=(TCWDS+TPD+TGPD)/(3)
5500 AFRW=(RPFR+FRW+GPFR)/(3)
5510 AFRS=(RPFR+FRS+GPFR)/(3)
5520 NADCW=(AFRW)*(19)
5530 NADCS=(AFRS)*(19)
5540 PEW=(NADCW-ADCW)/(DCWW)
5550 PES=(NADCS-ADCS)/(DCWS)
5555 IF WI=10 THEN 5760
5560 ADCW=(TCWD+TPD)/(2)
5570 ADCS=(TCWDS+TPD)/(2)
5580 AFRW=(FRW+RPFR)/(2)
```

```
5030 IF WI=6 THEN LPRINT "HOUSE PUMP SYSTEM WITH HOUSE .ANK":GO TU 5230
5040 IF WI=3 THEN LPRINT "PUMP SYSTEM WITH NO STORAGE":GO TO 6020
5050 IF WI=2 THEN LPRINT "HOME PUMP SYSTEM WITH NO STORAGE":GO TO 6020
5060 IF WI=1 THEN LPRINT "ROOF PUMP SYSTEM WITH NO STORAGE":GO TO 6020
5070 PRINT "INPUT THE NO. OF ROOF TANKS"
5080 INPUT Z
5090 IF W%(J,12)=0 THEN PC1=W%(J,9)*W%(J,11):GO TO 5105
5100 PC1=W%(J,9)*(W%(J,12)/7)
5105 IF Z=1 THEN 5150
5110 IF W%(J,16)=0 THEN PC2=W%(J,13)*W%(J,15):GO TO 5125
5120 PC2=(W%(J,17)*W%(J,16)/7)
5125 IF Z=2 THEN 5150
5130 IF W%(J,20)=0 THEN PC3=W%(J,17)*W%(J,19):GO TO 5150
5140 PC3=(W%(J,17)*W%(J,20)/7)
5150 TPC=PC1+PC2+PC3
5160 FOR Y=1 TO 3
5170 IF Y=1 THEN PD1=(0.1)*(TPC):GO TO 5200
5180 IF Y=2 THEN PD2=(0.033)*(TPC):GO TO 5200
5190 PD3=(0.06)*(TPC)
5200 NEXT Y
5210 TPD=(PD1*3+PD2*8+PD3*8)
5220 RPFR=(TPD/19)
5225 IF WI=9 THEN 5334
5230 IF W%(J,30)=0 THEN PGC=(W%(J,28)/W%(J,29)):GO TO 5250
5240 PGC=(W%(J,28)/(W%(J,30)*7))
5250 FOR Y=1 TO 3
5260 IF Y=1 THEN PGD1=(0.1)*(PGC):GO TO 5290
5270 IF Y=2 THEN PGD2=(0.033)*(PGC):GO TO 5290
5280 PGD3=(0.06)*(PGC)
5290 NEXT Y
5300 TGPD=(PGD1*3+PGD2*8+PGD3*8)
5330 GPFR=(TGPD/19)
5334 IF WI=6 THEN 5650
5335 NPT1=(0.00125)*(W%(J,11)+W%(J,15)+W%(J,19))
5336 NPT2=(0.00125*0.14286)*(W%(J,12)+W%(J,16)+W%(J,20))
5337 NPT=NPT1+NPT2
5338 TA=(10^-3)*(W%(J,9)+W%(J,13)+W%(J,17))
5340 QW=(7.95*10^-2)*(RPFR)
5350 QS=(12.14*10^-2)*(RPFR)
5360 EFW=(0.099662)*(RPFR/TA)
5370 EFS=(0.122737)*(RPFR/TA)
5380 LF=(1212)*(EFW-EFS)
5390 PCF=(27.898)*(RPFR/(TA*ABS(LF)))
5400 ENHW=(0.00247)*(THWD)
5410 ENHS=(0.00377)*(THWD)
5420 LEW=(10)*(TA*ABS(LF))
5430 LES=(20)*(TA*ABS(LF))
5440 HAUCW=(0.00268)*(LEW)
5450 HAUXS=(0.00377)*(LES)
5451 PCP=(0.35*0.7457)*(PCF*NPT)
5452 M=(0.75*31)*(PCP)
5460 TLW=HAUXW+ENHW
5470 TLS=HAUXS+ENHS
5471 IF WI=9 THEN 5560
5480 ADCW=(TCWD+TPD+TGPD)/(3)
5490 ADCS=(TCWDS+TPD+TGPD)/(3)
5500 AFRW=(RPFR+FRW+GPFR)/(3)
5510 AFRS=(RPFR+FRS+GPFR)/(3)
5520 NADCW=(AFRW)*(19)
5530 NADCS=(AFRS)*(19)
5540 PEW=(NADCW-ADCW)/(DCWW)
5550 PES=(NADCS-ADCS)/(DCWS)
5555 IF WI=13 THEN 5760
5560 ADCW=(TCWD+TPD)/(2)
5570 ADCS=(TCWDS+TPD)/(2)
5580 AFRW=(FRW+RPFR)/(2)
```

```
5590 AFRS=(FRS+RPFR)/(2)
5600 NADCW=(AFRW)*(19)
5610 NADCS=(AFRS)*(19)
5620 PEW=(NADCW-ADCW)/(DCWW)
5630 PES=(NADCS-ADCS)/(DCWS)
5640 IF WI =9 THEN 5760
5650 ADCW=(TCWD+TGPD)/(2)
5660 ADCS=(TCWDS+TGPD)/(2)
5670 AFRW=(FRW+GPFR)/(2)
5680 AFRS=(FRS+GPFR)/(2)
5690 NADCW=(AFRW)*(19)
5700 NADCS=(AFRS)*(19)
5710 PEW=(NADCW-ADCW)/(DCWW)
5720 PES=(NADCS-ADCS)/(DCWS)
5725 LPRINT "                         FAMILY INDEX=                    ";J
5730 LPRINT
5735 LPRINT "WI                   TI                   PI
5740 LPRINT
5745 LPRINT W1,TAB(25);TI;TAB(50);PI
5760 LPRINT "WATER CONSUMPTION AND DISTRIBUTION"
5770 LPRINT
5780 LPRINT "TOTAL CONSUPTION(L/DAY)------------------------------------------------
5790 LPRINT
5800 LPRINT TAB(25);TPC;TAB(35);TPD;TAB(45);PGC;TAB(55);TGPD
5810 LPRINT
5820 LPRINT "DISTRIBUTION (L/HR)---------6-8---------9-16-------------17-24---------
5830 LPRINT
5840 LPRINT TAB(25);PD1;TAB(35);PD2;TAB(45);PD3
5850 LPRINT TAB(25);PGD1;TAB(35);PGD2;TAB(45);PGD3
5860 LPRINT
5870 LPRINT "FLOW RATE(L/HR)---------------------------------------------------------
5880 LPRINT
5890 LPRINT TAB(25);RPFR;TAB(35);GPFR;TAB(45);AFRW;TAB(55);AFRS
5900 LPRINT
5901 LPRINT"CORRECTED AVERAGE OF DAILY CONSUMPTION(L/DAY)
5902 LPRINT
5903 LPRINT TAB(25);NADCW;TAB(55);NADCS
5904 LPRINT
5905 LPRINT "PERCENTAGE OF ERROR
5906 LPRINT
5907 LPRINT TAB(25);PEW;TAB(55);PES
5908 IF WI=6 THEN 6010
5910 LPRINT "TANK EFFICIENCY IN WINTER--------------------------------------------SUM
5915 LPRINT
5920 LPRINT TAB(25);EFW;TAB(65);EFS
5930 LPRINT
5940 LPRINT "TANK LOSS FACTOR (W/M^2 DEG.) -----------------------------------------
5950 LPRINT
5960 LPRINT TAB(34);LF
5970 LPRINT
5980 LPRINT
5990 LPRINT "TEPERATURE RATIO (TON/TOFF)----------------------------------------------
5991 LPRINT
5992 LPRINT TAB(34);PCF
5993 LPRINT
5994 LPRINT "ENHW(GJ)-------------ENHS(GJ)--------------LEW(W)-------------LES(W)"
5995 LPRINT
5996 LPRINT ENHW;TAB(20);ENHS;TAB(40);LEW;TAB(55);LES
5997 LPRINT
5998 LPRINT "HAUXW(GJ)-------------HAUXS(GJ)-------------TLW(GJ)-------------TLS(GJ)
5999 LPRINT
6000 LPRINT HAUXW;TAB(20);HAUXS;TAB(38);TLW;TAB(55);TLS
6001 LPRINT
6002 LPRINT "POWER COSUMED IN PUMPING PER DAY(KWHR)-----------------------------
6003 LPRINT
6004 LPRINT TAB(60);PCP
```

```
6005 LPRINT
6006 LPRINT "MONTHLY MONEY SPENT TO MEET THE LOAD(RAIL)--------------------"
6007 LPRINT
6008 LPRINT TAB(60);M
6010 RETURN
6020 LPRINT "DEVELOPE THE OTNER SYSTEM"
7000 RETURN
```

SOLAR RADIATION MODEL PROGRAM

```
5 DIM AZ(34,19)
10 INPUT "NAME OF DATA FILE";N$
15 OPEN N$ FOR OUTPUT AS FILE #1
20 IF N$='MON' GO TO 180
30 INPUT "INPUT DATE=";X
40 IF X>31 THEN GO TO 30
45 PRINT #1,X
50 INPUT "ENTER THE DATA OF THE 6TH HOUR";RZ
60 IF RZ=0 THEN GO TO 98
70 PRINT "MAKE SURE"
80 INPUT "ENTER DATA OF THE 6TH HOUR AGAIN";SZ
96 IF SZ > 0 THEN 100
97 IF SZ < 0 THEN 102
98 PRINT #1,RZ;','
99 GO TO 105
100 PRINT #1,SZ;','
101 GO TO 105
102 PRINT #1,SZ;','
103 GO TO 105
105 FOR Y=7 TO 19
110 LET SZ=RZ
120 PRINT "ENTER DATA FOR HOUR"; Y
130 INPUT RZ
135 IF RZ<0 THEN AZ(X,Y)=-1
136 IF RZ<0 THEN RZ=ABS(RZ)
137 IF RZ=0 GO TO 150
140 IF RZ<SZ GO TO 120
141 IF RZ>SZ THEN AZ(X,Y)=RZ-SZ
145 PRINT AZ(X,Y),
150 NEXT Y
151 PRINT X
152 FOR Y=7 TO 19
153 PRINT #1,AZ(X,Y)
154 NEXT Y
155 CLOSE #1
170 PRINT
175 GO TO 10
180 END
```

```
900 DIM AZ(34,19)
901 PRINT"STATION-----------            TYPE OF RADIATION----------------"
902 PRINT"LAT----LON------                                  MON---YR-----"
910 PRINT"--------------------------------------------------------------------------------
920 PRINT"DAY-------6-----7-----8-----9-----10-----11-----12-----13-----14-----15-----16-----
930 PRINT"--------------------------------------------------------------------------------
945  DY=0
955 INPUT 'ENTER FILE DATA NAME';N$
956 IF N$='MON' GO TO 1131
960 DY=DY+1
1000 OPEN N$ FOR INPUT AS FILE #1
1016 INPUT #1,X
1017 PRINT X;
1090 FOR Y=6 TO 19
1092 INPUT #1,AZ(X,Y)
1100 REM PRINT AZ(X,Y);
1110 NEXT Y
1115 PRINT
1120 CLOSE #1
1130 GOTO 955
1132 FOR X=1 TO DY
1133 FOR Y=6 TO 19
1131 PRINT X;
1134 PRINT TAB((Y-6)*7+8);AZ(X,Y);
1135 NEXT Y
1136 NEXT X
1261 PRINT"--------------------------------------------------------------------------------
2010 PRINT "TOTAL";
2012 TMEAN=0
2015 FOR Y=6 TO 19
2016 LET TOTAL=0
2030 LET C=0
2040 FOR X=1 TO DY
2050 IF AZ(X,Y)<0 GOTO 2080
2051 REM IF AZ(X,0)=0 GOTO 2090
2060 LET TOTAL=TOTAL+AZ(X,Y)
2070 LET C=C+1
2080 NEXT X
2090 LET AZ(34,Y)=TOTAL/C
2091 TMEAN=TMEAN+AZ(34,Y)
2092 IF L=3 GO TO 2150
2093 IF L=2 GO TO 2100
2095 PRINT TAB((Y-6)*7+8);TOTAL;
2096 GO TO 2200
2100 PRINT TAB((Y-6)*7+8);C;
2101 GO TO 2200
2150 PRINT TAB((Y-6)*7+8);AZ(34,Y);
2200 NEXT Y
```

```
2201 IF L=2 GO TO 2400
2202 IF L=3 THEN 2450
2300 L=2
2310 PRINT
2315 PRINT "COUNT";
2320 GO TO 2015
2400 L=3
2401 PRINT
2415 PRINT "MEAN";
2420 GO TO 2012
2450 PRINT "TMEAN="; TMEAN
2460 END
```

```
10 DIM A(4),B(7),D(365)
20 FOR S=1 TO 4
30 READ A(S)
40 DATA 0.386470,-0.792624,0.377853,0.030124
50 NEXT S
51 FOR M=1 TO 7
52 READ B(M)
53 DATA 1.1049,-1.4354,-1.0720,6.6849,-13.8990,13.0798,-4.4631
54 NEXT M
60 FOR Y=1 TO 365
70 T=(3.142/180)*(360/365)*(Y-80)
75 T1=(3.142/180)*(360/365)*(Y-196)
76 W=.845+.0115*SIN(T1)
80 S=1
90 D=A(S)+A(S+1)*(COS(T)-29.345*SIN(T))+A(S+2)*(COS(2*T)+.348*SIN(2*T))
100 D1=A(S+3)*(COS(3*T)-5.544*SIN(3*T))
110 D(Y)=D+D1
120 PRINT Y,D(Y)
125 DEC=(3.142/180)*D(Y)
130 COSD=COS(DEC):SIND=SIN(DEC)
140 L=15:LR=(3.142/180)*L:COSL=COS(LR):SINL=SIN(LR)
150 FOR K=1 TO 14
160 HA=(12.5-(K+5))*15*(3.142/180)
170 SINH=SIN(HA):COSH=COS(HA)
180 X=COSL*COSH*COSD+SINL*SIND
190 SAL=ATN(X/SQR(1-X^2))
200 PRINT "SAL=";SAL*(180/3.142)
210 Z=(1-(2/3.142)*SAL)
220 IF SAL<=0 THEN GR=0:GOTO 260
225 IF SAL<=0 THEN DSR=0:GOTO 260
230 GR1=W*(1.1049-1.4354*(Z^2)-1.072*(Z^4)+6.6849*(Z^6)-13.899*(Z^8))
240 GR2=W*(13.0798*(Z^10)-4.4631*(Z^12))
250 GR=GR1+GR2:GR=GR*1000
255 DTGR=DTGR+GR
256 DSR1=W*(.9964-.2001*(Z^2)-1.1883*(Z^4)+3.3706*(Z^6)-5.5674*(Z^8))
257 DSR2=W*(3.7206*(Z^10)-.9213*(Z^12))
258 DSR=DSR1+DSR2:DSR=DSR*1000
259 DTDSR=DTDSR+DSR:DFSR=GR-DSR*X:DTDFR=DTDFR+DFSR
260 PRINT K+5;TAB(5);Y;TAB(10);W;TAB(20);Z;TAB(30);GR;TAB(40);DSR;TAB(50
265 GR1=0:GR2=0:GR=0:DSR1=0:DSR2=0:DSR=0:DFSR=0
270 NEXT K
275 PRINT "DTGR(WHR/M*M DAY)=";DTGR;"DTGR(MJ/M*M DAY)=";DTGR*(3.6/1000)
276 PRINT "DTDSR(Whr/SQ.M DAY)=";DTDSR;"DTDSR(MJ/SQ.M.DAY)=";DTDSR
277 PRINT"DTDFR(WHR/SQ.M DAY)=";DTDFR;"DTDFR(MJ/SQ.M.DAY)=";DTDFR
278 DTGR=0:DTDSR=0:DTDFR=0
280 V=(15-12.5)/7.5
290 C1=26.789453#-.760391*V-.265078*(V^2)-.007734*(V^3)
300 C2=.092481-.050012*V+.004731*(V^2)-.00619*(V^3)
310 C3=1.209688-.025625*V-8.437999E-03*(V^2)-.005625*(V^3)
320 C4=.018456-.025926*V-.013168*(V^2)+.015157*(V^3)
330 C5=3.172571+2.431533*V+.008367*(V^2)-.012203*(V^3)
340 C6=.112969+.075469*V+.007031*(V^2)-.037969*(V^3)
350 C7=-.064616+.071846*V+.005554*(V^2)-.037515*(V^3)
360 H=C1+C2*COS(T)+C3*COS(2*T)+C4*COS(3*T)+C5*SIN(T)+C6*SIN(2*T)+C7*SIN(T)
370 PRINT Y,H
380 NEXT Y
```

HEAT LOSS MODEL PROGRAM

```
10 DIM UW(8),FW(8),DW(8),ABW(8),LHD1(8),LHD2(8),CLB1(8),CLB2(8),ETA(8)
15 DIM UR(9),FR(9),DR(9),ABR(9),URA(9)
20 DIM H(12),SE(12),SN(12),SS(12),SNE(12),SSE(12),TA(12),N(12),SF(12),TF(12)
25 DIM G(8,9)
30 DIM DD(12),DDC(12),QH(12),QC(12),QL(12),TT(12),QTH(12),QABW(12)
40 DIM FS(12),QABR(12),EEH(12),TNH(12),TI(12),QU(12),QAX(12),EFF(12)
50 DIM QST(12),TS(12),QT(12),QTW(12),QAC(12)
200 PRINT"ENTER CITY CODE:TYPE 0 FOR YEMEN; 1 FOR U.K. ;3 FOR GREECE"
210 INPUT CC
220 PRINT"ENTER RUN INDEX ACCORDINT TO THE FOLLOWING TABLE"
230 PRINT"RUN INDEX          OPTIONS                              "
235 PRINT"   1                MASSIVE WALLS+HORZ.ROOF             "
240 PRINT"   2                BUFFER(GARAGE)+CASE 1               "
245 PRINT"   3                BUFFER(SUNSPACE)+CASE1              "
250 PRINT"   4                TWO BUFFERS(GARAGE+SUNSPACE)+CASE1"
260 PRINT"   5                SUNSPACE COUPLED WITH AIRCOND.+CASE1"
265 PRINT"   6                OPEN LOOP SOLAR WALL+CASE1          "
270 PRINT"   7                TROMBE WALL+CASE1                   "
275 PRINT"   8                OPEN LOOP SOLAR COLL.INST.ON ROOF+CASE1"
280 PRINT"ENTER RUN INDEX":INPUT RI
530 FOR H=1 TO 8
540 READ UW(H),FW(H),DW(H),ABW(H),LHD1(H),LHD2(H),CLB1(H),CLB2(H)
550 DATA 1.47,0.05,0.52,0.4,12.5,18.7,0.94,0.89
560 DATA 1.29,0.07,0.42,0.6,11.0,17.3,0.94,0.90
570 DATA 3.36,0.06,0.45,0.65,26.3,32.5,0.87,0.81
580 DATA 0.72,0.04,0.62,0.64,6.30,12.5,0.97,0.92
590 DATA 5.34,0.45,0.17,0.65,38.7,44.5,0.80,0.74
600 DATA 2.89,0.28,0.22,0.64,23.1,29.3,0.88,0.83
610 DATA 2.93,0.14,0.32,0.4,23.2,29.6,0.88,0.83
620 DATA 5.19,0.17,0.29,0.4,37.9,43.7,0.81,0.75
630 NEXT H
631 FOR H=1 TO 8
632 READ ETA(H)
633 DATA 0.085,0.07,0.105,0.045,0.105,0.105,0.105,0.105
634 NEXT H
636 RA=1.06
640 FOR M=1 TO 9
650 READ UR(M),FR(M),DR(M),ABR(M)
660 DATA 2.26,0.45,0.15,0.6
670 DATA 2.10,0.45,0.15,0.6
680 DATA 1.83,0.50,0.13,0.6
690 DATA 2.11,0.42,0.14,0.65
700 DATA 2.72,0.45,0.15,0.65
710 DATA 10.32,0.45,0.15,0.65
720 DATA 7.72,0.27,0.22,0.65
730 DATA 2.86,0.19,0.28,0.65
740 DATA 2.30,0.10,0.36,0.65
745 URA(M)=UR(M)/(1+RA*UR(M))
750 NEXT M
760 FOR J=1 TO 12
770 READ H(J),SE(J),SN(J),SS(J),SNE(J),SSE(J),TA(J),N(J)
780 DATA 5.52,2.10,0.18,4.26,0.36,3.24,15.90,31
790 DATA 6.24,2.40,0.24,3.36,0.72,2.88,18.20,28
800 DATA 7.10,2.64,0.24,1.92,1.20,2.40,18.20,31
810 DATA 7.80,2.76,0.60,0.36,1.92,1.80,20.30,30
820 DATA 7.80,2.88,1.80,0.24,2.40,1.32,22.00,31
830 DATA 7.80,2.76,2.40,0.24,2.64,1.08,22.80,30
840 DATA 7.80,2.88,1.80,0.24,2.40,1.32,23.20,31
850 DATA 7.80,2.76,0.60,0.36,1.92,1.80,22.50,31
860 DATA 7.10,2.64,0.24,1.92,1.20,2.40,19.80,30
870 DATA 6.24,2.40,0.24,3.36,0.72,2.88,17.80,31
880 DATA 5.52,2.10,0.18,4.26,0.36,3.24,16.10,30
890 DATA 5.16,1.98,0.18,4.50,0.24,3.24,14.30,31
920 NEXT J
```

```
925 FOR J=1 TO 12
926 READ SF(J),TF(J)
927 DATA 0.555,1.26,0.396,1.097,0.416,0.974,0.437,0.839,0.452,0.766,0.458
928 DATA 0.452,0.763,0.437,0.837,0.416,0.982,0.395,1.11,0.555,1.27,0.549,1
929 NEXT J
1370 IF RI=1 THEN GOSUB 5000
1380 IF RI=2 THEN GOSUB 5500
1390 IF RI=3 THEN GOSUB 6000
1395 IF RI=3 THEN 9500
1400 IF RI=4 THEN GOSUB 6500
1405 IF RI=4 THEN 9500
1410 IF RI=5 THEN GOSUB 7000
1415 IF RI=5 THEN 9500
1420 IF RI=6 THEN GOSUB 7500
1430 IF RI=7 THEN GOSUB 8000
1440 IF RI=8 THEN GOSUB 9000
1442 IF WC=2 THEN 1444
1443 PRINT"ENTER WALL,ROOF CONSTRUCTION NUMBER":INPUT H,M
1444 FOR J=1 TO 12
1445 IF J<=3 THEN TT=18:GOTO 1448
1446 IF J>=10 THEN TT=18:GOTO 1448
1447 TT=22
1448 DD(J)=(TT-TA(J))*N(J):DDC(J)=(TA(J)-TT)*N(J)
1449 IF DD(J)<0 THEN DD(J)=0
1450 IF DDC(J)<0 THEN DDC(J)=0
1451 QH(J)=.024*G(H,M)*V*DD(J)
1452 QC(J)=.024*G(H,M)*V*DDC(J)
1453 QL(J)=QC(J)+QH(J)
1454 TT(J)=TT:NEXT J
1455 PRINT"MONTH INSIDE TEMP          ENERGY IN (KWH)                    "
1456 PRINT"      WITHOUT WITH        USEFUL        LOAD        AXULAR       "
1457 PRINT"      AXULAR  AXU                                                "
1460 IG=.13*AF
1470 FOR J=1 TO 12
1480 QDG=(AGE+AGW)*SE(J)+AGN*SN(J)+AGS*SS(J):QTH(J)=QDG*SF(J)
1486 IF WC=2 THEN UW=UW1:GOTO 1488
1487 UW=UW(H)
1488 IF WC=2 THEN ABW=.6:GOTO 1490
1489 ABW=ABW(H)
1490 IF WC=2 THEN FW=.45:GOTO 1495
1491 FW=FW(H)
1495 QABW=UW*ABW*FW*.22*((AWE+AWW)*SE(J)+AWN*SN(J)+AWS*SS(J))
1500 QABW(J)=QABW
1505 IF WC=2 THEN ABR=.6:GOTO 1525
1510 IF TR=2 THEN ABR=.3:GOTO 1525
1520 ABR=ABR(M)
1525 IF WC=2 THEN UR=UR1:GOTO 1550
1530 IF TR=3 THEN UR=URA(M):GOTO 1550
1540 UR=UR(M)
1550 IF WC=2 THEN  FR=.5:GOTO 1555
1551 FR=FR(H)
1555 QABR=UR*FR*ABR*.22*AF*H(J):QABR(J)=QABR
1570 QHH=QTH(J)+IG+QABW(J)+QABR(J)
1580 IF RI=1 THEN EEH=QHH:GOTO 1680
1590 IF RI=2 THEN EEH=QHH:GOTO 1680
1600 IF RI=3 THEN EEH=QHH+QST(J):GOTO 1680
1620 IF RI=4 THEN EEH=QHH+QST(J):GOTO 1680
1640 IF RI=5 THEN EEH=QHH+QST(J):GOTO 1680
1660 IF RI=6 THEN EEH=QHH+QT(J):GOTO 1680
1670 IF RI=7 THEN EEH=QHH+QTW(J)
1675 IF RI=8 THEN EEH=QTH(J)+IG+QABW(J)+(QABR(J)-AC*H(J)*TF(J))+QAC(J)
1680 EEH(J)=QHH
1690 TNH(J)=TA(J)+EEH(J)/(.024*V*G(H,M))
1691 X=TT-TNH(J)
1692 IF H<=4 THEN GOSUB 10000
1693 IF H>4 THEN GOSUB 10500
```

```
1695 QU(J)=(EFF/100)*EEH(J)*N(J)
1696 IF QL(J)=0 THEN QAX(J)=0:GOTO 1700
1698 QAX(J)=QL(J)-QU(J)
1700 IF QL(J)=0 THEN TI(J)=TNH(J):GOTO 1710
1705 TI(J)=TA(J)+EEH(J)/(.024*G(H,M)*V)+(QAX(J)/QL(J))*(TT(J)-TA(J))
1710 EFF(J)=EFF
1715 PRINT J;TAB(5);INT(TNH(J));TAB(15);INT(TI(J));TAB(30);INT(QU(J))
1716 PRINT INT(QL(J));TAB(50);INT(QAX(J));TAB(60);INT(DD(J));TAB(70)
1720 NEXT J
1725 PRINT"WOULD LIKE A PRINT OUT:TYPE 1 FOR YES,0 FOR NO":INPUT PI
1726 IF PI=0 THEN 2610
1730 LPRINT"RUN INDEX                               TYPE OF ROOF"
1735 LPRINT RI;TAB(45);TR
1737 LPRINT:LPRINT:LPRINT:LPRINT
1738 LPRINT"     DESIGN CHARACTERISTICS OF THE CONSIDERED CASE
1739 LPRINT"    SOLID  WALL AREA          GLAZED     AREA        ROOF AREA
1740 LPRINT"EAST    WEST  NORTH SOUTH   EAST  WEST  NORTH SOUTH
1741 LPRINT
1742 LPRINT AWE;TAB(10);AWW;TAB(20);AWN;TAB(30);AWS;TAB(40);AGE;TAB(50);AGW
1743 LPRINT TAB(60);AGN;TAB(65);AGS;TAB(70);AF;TAB(75);V
1756 LPRINT"TABLE2:EFFECT OF WALL/ROOF INSULATION AND PASSIVE FEATURES ON "
1757 LPRINT"                HEATING/COOLING LOADS OF THE HOUSE           "
1760 LPRINT"WALL ROOF MONTH DEGREE-DAYS  AMBIENT      LOAD IN (KWH)      "
1770 LPRINT"TYPE TYPE       HEATING COOL AIR TEMP.   HEATING COOLING TOTAL"
1780 LPRINT"-----------------------------------------------------------------"
1790 LPRINT
1800 LPRINT H;
1820 LPRINT TAB(5);M;
1830 FOR J=1 TO 12
1840 LPRINT TAB(10);J;TAB(15);DD(J);TAB(25);DDC(J);TAB(35);TA(J);TAB(45);
1850 LPRINT QH(J);TAB(55);QC(J);TAB(65);QL(J);
1855 DDT=DDT+DD(J):DDCT=DDCT+DDC(J):QHT=QHT+QH(J):QCT=QCT+QC(J):QLT=QLT+QL
1856 QLT=QLT+QL(J)
1860 LPRINT
1870 NEXT J
1880 LPRINT"---------------------------------------------------------------"
1900 LPRINT TAB(15);DDT;TAB(25);DDCT;TAB(45);QHT;TAB(55);QCT;TAB(65);QLT/2
1910 LPRINT:LPRINT:LPRINT:LPRINT:LPRINT
1920 LPRINT"TABLE3:EFFECT OF WALL-ROOF COUPLING ON HEAT GAINS
"
1930 LPRINT"WALL ROOF MONTH        ENERGY GAINS IN (KWH/DAY) "
1940 LPRINT"TYPE TYPE              TRANSMITTED     ABSORBED  "
1950 LPRINT"                .      VIA WINDOWS  WALL  ROOF  "
1960 LPRINT"---------------------------------------------------"
1970 LPRINT
1990 LPRINT H;
2010 LPRINT TAB(5);M;
2020 FOR J=1 TO 12
2030 LPRINT TAB(10);J;TAB(15);QTH(J);TAB(30);QABW(J);TAB(45);QABR(J);
2040 LPRINT TAB(60);EEH(J);
2045 TEEH=TEEH+EEH(J)
2050 LPRINT
2060 NEXT J
2065 LPRINT"-----------------------------------------------------------------"
2100 LPRINT TAB(60);TEEH
2110 LPRINT:LPRINT:LPRINT:LPRINT
2120 LPRINT"TABLE5:EFFECT OF WALL-ROOF COUPLING ON THE USEFUL ENERGY GAINS
2130 LPRINT"WALL ROOF MONTH     ENERGY       USEFUL       AUX
2140 LPRINT"TYPE TYPE           ENTERED       GAIN                       "
2150 LPRINT"               TO THE HOUSE
2160 LPRINT"                  ( KWHR  )    (KWHR)                 (KWHR)    "
2170 LPRINT"-----------------------------------------------------------------"
2185 LPRINT H;
2190 LPRINT TAB(5);M;
2200 FOR J=1 TO 12
2210 LPRINT TAB(10);J;TAB(15);EEH(J)*N(J);TAB(30);QU(J);TAB(45);
2220 LPRINT QAX(J)
2225 IF QAX(J)<0 THEN QAX(J)=ABS(QAX(J))
```

```
2230 LPRINT
2240 NEXT J
2250 LPRINT"-----------------------------------------------------------------"
2255 LPRINT TAB(30);TQU;TAB(45);TAX
2290 LPRINT:LPRINT:LPRINT:LPRINT:LPRINT
2300 LPRINT"TABLE4:EFFECE OF WALL-ROOF COUPLING ON THE EFF AND INSIDE TEMP"
2310 LPRINT"WALL ROOF MONTH  EFFICIENCY INSIDE HOUSE TEMP.  TEMP.INCREASE"
2320 LPRINT"                                    ( C )             ( C )    "
2325 LPRINT"                              WITHOUT AX    WITH AX           "
2330 LPRINT"------------------------------------------------------------------
2340 LPRINT
2360 LPRINT H;
2380 LPRINT TAB(5);M;
2390 FOR J=1 TO 12
2400 LPRINT TAB(10);J;TAB(15);EFF(J);TAB(25);TA(J);TAB(35);TNH(J);TAB(45);
2405 IF QL(J)=0 THEN DELT=EEH(J)/(.024*G(H,M)*V):GOTO 2420
2410 DELT=EEH(J)/(.024*G(H,M)*V)+(QAX(J)/QL(J))*(TT(J)-TA(J))
2420 LPRINT TI(J);TAB(55);TT(J);TAB(65);DELT
2430 LPRINT
2435 TNHT=TNHT+TNH(J):TIT=TIT+TI(J):DELTT=DELTT+DELT:EFFT=EFFT+EFF(J)
2440 NEXT J
2450 LPRINT"-----------------------------------------------------------------"
2455 LPRINT TAB(20);EFFT/12;TAB(40);TNHT/12;TAB(50);TIT/12;TAB(60);DELTT
2456 DDT=0:DDCT=0:QHT=0:QCT=0:QLT=0:TEEH=0:TQU=0:TAX=0:TNHT=0:TIT=0
2457 EFFT=0
2490 FOR J=1 TO 12
2500 QTH(J)=0:QABW(J)=0:QABR(J)=0:EEH(J)=0:TNH(J)=0:QU(J)=0
2510 QAX(J)=0:EFF(J)=0:TI(J)=0
2550 NEXT J
2610 IF H>1 THEN 2655
2611 IF M>1 THEN 2655
2612 FOR H=1 TO 8
2613 IF PI=0 THEN 2620
2615 LPRINT H;
2620 FOR M=1 TO 9
2625 IF PI=0 THEN 2650
2630 LPRINT TAB(10);1/UW(H);TAB(30);1/UR(M);TAB(45);G(H,M);
2635 LPRINT
2640 NEXT M
2650 NEXT H
2655 PRINT"WOULD YOU LIKE TO CHANGE WALL/ROOF CONST.MAT."
2656 PRINT"ENTER 1 IF YES 0 IF NO":INPUT RR
2657 IF RR=1 THEN 1442
2660 PRINT"WOULD YOU LIKE ANOTHER OPTION:TYPE 1 FOR YES,0 FOR NO"
2670 INPUT RII
2680 IF RII=1 THEN 2691
2690 END
2691 FOR H=1 TO 8
2692 FOR M=1 TO 9
2693 G(H,M)=0
2694 NEXT M
2695 NEXT H
2700 PRINT"RUN INDEX         OPTIONS"
2710 PRINT"    1             HOUSE  "
2720 PRINT"    2             HOUSE +GARAGE"
2730 PRINT"    3             HOUSE+SUNSPACE"
2740 PRINT"    4             HOUSE+GARAGE+SUNSPACE"
2750 PRINT"    5             HOUSE+SUNSPACE COUPLED WITH AIR EXCHANGER"
2760 PRINT"    6             OPEN LOOP SOLAR WALL INST.ON THE SOUTH+HOUSE"
2770 PRINT"    7             TROMBE WALL              ====================="
2780 PRINT"    8             OPEN LOOP SOLAR COLLECTOR INST ON ROOF+HOUSE"
2790 INPUT RI:GOTO 1370
5000 AW=90:AG=6.24:AF=48:AD=2.1:LF=7.58:V=167.503
5010 AWE=21.4:AWW=20.7:AWN=24.4:AWS=23.3
5020 AGE=1.2:AGW=1.92:AGN=0:AGS=3.12
5025 PRINT"ENTER TYPE OF ROOF:1 ORDINARY,2 WITH WHITE TILE,3 WITH AIR SPA"
```

```
5030 PRINT"ENTER WALL/ROOF CODE:1 FOR YEMENI WALLS/ROOFS,2 INTERNATIONAL"
5035 IF WC=1 THEN 5045
5036 PRINT"ENTER UWALL,UROOF,AND UWINDOW":INPUT UW1,UR1,UWIN
5037 G1=AW*UW1+AF*UR1+AG*UWIN+3.33*AD+2.1*LF+.34*V
5038 IF RI=8 THEN G1=G1-.34*EFFC*Q
5039 G1=G1/V
5040 GOTO 5140
5045 FOR H=1 TO 8
5050 FOR M=1 TO 9
5060 IF TR=3 THEN UR=URA(M):GOTO 5075
5070 UR=UR(M)
5075 X2=.34*EFFC*Q
5080 G=AW*UW(H)+AF*UR+AG*4.3+AD*3.33+2.1*LF+.34*V
5085 IF RI=8 THEN G=G-X2
5090 G(H,M)=G/V
5120 NEXT M
5130 NEXT H
5135 IF RI=8 THEN 9210
5136 PRINT"ENTER PRINT INDEX:TYPE 1 TO PRINTER,0 OTHERWISE"
5137 INPUT PI
5138 IF PI=0 THEN 5210
5140 LPRINT" TABLE( ):CHARACTERISTICS OF THE INPUTTED HOUSE"
5145 LPRINT"SOLID WALL AREA IN(SQ.M.):  EAST    WEST  NORTH   SOUTH      TO
5150 LPRINT TAB(20);AWE;TAB(30);AWW;TAB(40);AWN;TAB(50);AWS;TAB(60);AW
5160 LPRINT
5170 LPRINT"WWINDOW AREA IN(SQ.M.)     :                                   "
5175 LPRINT TAB(20);AGE;TAB(30);AGW;TAB(40);AGN;TAB(50);AGS;TAB(60);AG
5180 LPRINT"ROFF AREA            VOLUME                G_FACTOR"
5185 LPRINT"(SQ.M.)             (CUBIC M)              (W/CMC)  "
5190 LPRINT AF;TAB(35);V;TAB(55);G1
5195 LPRINT:LPRINT:LPRINT
5200 LPRINT"-----------------------------------------------------------------"
5210 RETURN
5500 AW=80.75:AG=6.24:AF=48.13301:AD=2.1:LF=7.6:V=167.503
5510 AWE=21.4:AWW=20.7:AWN=12.2:AWS=23.3
5520 AGE=1.2:AGW=1.92:AGN=0:AGS=3.12
5525 PRINT"ENTER TYPE OF ROOF:1 ORDINARY,2WITH WHITE PAINT,3 WITH AIR SPACE
5530 PRINT"ENTER WALL/ROOF CODE:1 FOR YEMENI WALLS/ROOFS,2 INTERNATIONAL"
5540 IF WC=2 THEN PRINT"ENTER UWALL,UROOF,UWIN":INPUT UW1,UR1,UWIN:GOTO 560
5550 FOR H=1 TO 8
5560 FOR M=1 TO 9
5570 IF TR=3 THEN UR=URA(M):GOTO 5585
5580 UR=UR(M)
5585 X1=1-CLB1(H)
5590 G=UW(H)*AW+UR*AF+4.3*AG+3.33*AD+2.1*LF+.34*(V-X1*30)+LHD1(H)
5595 G=G/V:G(H,M)=G
5598 NEXT M
5599 NEXT H:GOTO 5695
5600 G1=UW1*AW+UR1*AF+UWIN*AG+2.1*LF+3.33*AD+.34*(V-CLB1(8)*30)+LHD1(8)
5610 G1=G1/V
5695 RETURN
6000 PRINT"ENTER TYPE OF BUFFER:TYPE 1 FOR NON-TRANS,2 FOR TRANS.PARENT"
6010 PRINT"ENTER TYPE OF ROOF:1 ORDIN,2WHITE PAINT,3 AIR SPACE":INPUT TR
6020 PRINT"ENTER WALL/ROOF CODE:1 FOR YEMENIS,2 INTEERNATIONAL":INPUT WC
6030 PRINT"ENTER DIRECTION OF THE WINDOW BETWEEN HEATED AND SUNSPACE"
6035 PRINT" TYPE 1 FOR EAST/WEST DIRECTIONS,2 FOR NORTH,3 FOR SOUTH"
6040 AW=79.75:AG=4.8:AD=2.1:AF=48.13301:V=167.503:LF=7.6
6045 AWE=21.4:AWW=20.7:AWN=24.4:AWS=13.28
6050 AGE=1.2:AGW=1.92:AGN=0:AGS=1.68
6055 PRINT"ENTER NUMBER OF COLLECTING SURFACES":INPUT NCS
6056 PRINT"ENTER AREA OF THE COLLECTING SURFACES IN THE FOLLOWING ORDER"
```

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6057 PRINT"EAST,WEST,NORTH,AND SOUTH":INPUT AGSE,AGSW,AGSN,AGSS
6058 PRINT"ENTER AREA OF THE WINDOW BETWEEN SUNSPACE,AND HEATED SPACE"
6059 INPUT AGSH
6060 IF WC=1 THEN 6100
6065 PRINT"ENTER UW,UROOF,UWIN":INPUT UW1,UR1,UWIN
6070 IF RI=5 THEN X1=.34*V(1-.4*(90/V)-.4*(1-CLB2(8))*(90/V)):GOTO 6080
6075 X1=.34*V*(1-(90/V)*(1-CLB2(8)))
6080 G1=UW1*AW+UR1*AF+UWIN*AG+3.33*AD+2.1*LF+X1
6090 G1=G1/V:GOTO 6200
6100 FOR H=1 TO 8
6120 FOR M=1 TO 9
6130 IF TR=3 THEN UR=URA(M):GOTO 6150
6140 UR=UR(M)
6150 IF RI=5 THEN X1=.34*V*(1-.4*(90/V)-.4*(1-CLB2(H))*(90/V)):GOTO 6170
6160 X1=.34*V*(1-(90/V)*(1-CLB2(H)))
6170 G=UW(H)*AW+UR*AF+3.33*AD+4.3*AG+2.1*LF+X1
6180 G=G/V:G(H,M)=G
6195 NEXT M
6196 NEXT H
6285 IF RI=5 THEN 7010
6290 RETURN
6500 AW=70.7:AG=4.8:AD=2.1:LF=7.6:V=167.503:AF=48
6510 AWE=21.4:AWW=20.7:AWN=15.3
6520 AGE=1.2:AGW=1.92:AGN=0:AGS=1.68
6525 AWS=7.6*3.48-AGS-AGSS
6530 PRINT"ENTER NO.OF COLLECTING SURFACES":INPUT NCS
6531 PRINT"ENTER AREA OF THE COLLECTING SUR.IN EAST,WEST,NORTH,AND SOUTH"
6532 INPUT AGSE,AGSW,AGSN,AGSS
6533 PRINT"ENTER DIRECTION OF THE WINDOW BETWEEN SUNSPACE AND H.SPACE"
6534 PRINT"TYPE 1=E/W,2=N,3=S":INPUT DR
6535 PRINT"AREA OF THE WINDOW":INPUT AGSH
6540 PRINT"ENTER ROOF TYPE:1 ORDIN,2 WITH WP,3 WITH A.S.":INPUT TR
6550 PRINT"ENTER TYPE OF SUNSPACE:1 NONTRANS,2TRANS":INPUT TB
6560 PRINT"ENTER DIRECTION OF WINDOW BETWEEN S.S AND H.S.":INPUT DR
6570 PRINT"ENTER ROOF CODE:1 YEMENI,2 INTERNATIONA":INPUT WC
6580 IF WC=1 THEN 6640
6590 X1=.34*V*(1-(30/V)*(1-CLB1(8))-(90/V)*(1-CLB2(8)))
6600 PRINT"ENTER UWALL,UROOF,UWIN":INPUT UW1,UR1,UWIN
6610 G1=UW1*AW+UR11*AF+3.33*AD+UWIN*AG+2.1*LF+LHD1(8)+LHD2(8)+X1
6620 G1=G1/V
6630 GOTO 6800
6640 FOR H=1 TO 8
6660 FOR M=1 TO 9
6670 IF TR=3 THEN UR=URA(M):GOTO 6685
6680 UR=UR(M)
6685 X1=.34*V(1-(30/V)*(1-CLB1(H))-(90/V)*(1-CLB2(H)))
6690 G=UW(H)*AW+UR*AF+3.33*AD+2.1*LF+4.3*AG+X1+LHD1(H)+LHD2(H)
6700 G=G/V:G(H,M)=G
6730 NEXT M
6740 NEXT H
6820 RETURN
7000 IF RI=5 THEN 6000
7010 RETURN
7500 AW=78.4:AG=6.24:AF=48.13301:AD=2.1:V=167.503:LF=7.6
7510 AWE=20.7:AWW=20.22:AWN=24.35
7520 AGE=1.92:AGW=2.4:AGN=0:AGS=1.92
7525 IF RI=7 THEN 7540
7530 PRINT"ENTER AREA OF O.L.S.W.":INPUT ASW:QSW=10*ASW
7535 AWS=7.6*3.48-AGS-ASW
7540 PRINT"ENTER TYPE OF ROOF,1 ORDINARY,2 WHITE P.,3 A.S":INPUT TR
7545 PRINT"ENTER WALL/ROOF CODE,1 FOR YEMENI,2 INTERNATIONAL":INPUT WC
7550 IF WC=1 THEN 7600
7555 PRINT"ENTER UW,UR,UWIN":INPUT UW1,UR1,UWIN
7560 G1=UW1*AW+UR1*AF+UWIN*AG+3.33*AD+2.1*LF+.34*V*(1-(QSW/V)*ETA(8))
7565 G1=G1/V
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```
7575 LPRINT V;TAB(30);AF;TAB(40);G1
7580 LPRINT"-------------------------------------------------------------"
7590 GOTO 7665
7600 FOR H=1 TO 8
7615 FOR M=1 TO 9
7620 IF TR=3 THEN UR=URA(M):GOTO 7630
7625 UR=UR(M)
7630 G=UW(H)*AW+UR*AF+4.3*AG+3.33*AD+2.1*LF+.34*V*(1-(QSW/V)*ETA(H))
7640 G(H,M)=G/V
7655 NEXT M
7660 NEXT H
7665 IF RI=7 THEN 8225
7666 PRINT"SPECIFY THE CONST.MATERIAL OF THE OPEN LOOP SOLAR WALL(1 TO 8)"
7667 INPUT H
7670 ABW=ABW(H)
7680 FOR J=1 TO 12
7690 F=ASW*ABW*.8*SS(J)
7695 IF WC=1 THEN 7710
7700 ETA=ETA(8):X1=(1+.11*UW1)/(UW1*ASW):GOTO 7750
7710 ETA=ETA(H):X1=(1+.11*UW(H))/(UW(H)*ASW)
7750 QASW=.34*QSW*ETA*F*.9*X1
7760 IF WC=2 THEN UW=UW1:GOTO 7780
7770 UW=UW(H)
7780 QWSW=F*UW*.22*.9
7790 QT(J)=QASW+QWSW:PRINT"QT=";QT(J)
7795 NEXT J
7800 RETURN
8000 PRINT"ENTER AREA OF TRMBE WALL":INPUT ATW
8010 PRINT"SPECIFY THE EMISSIVITY OF THE ABSORBER(0.1 OR 0.9)":INPUT EM
8020 PRINT"SPECIFY THE NATURE OF GLAZING:1 SINGLE,2 DOUBLE":INPUT NG
8030 PRINT"IS THERE AN INSULATTING SHUTTER AT NIGHT(1 YES,0 NO)":INPUT NI
8040 IF NG=1 THEN 8100
8050 IF EM=.9 THEN 8070
8060 IF NI=1 THEN C=.8499999:GOTO 8220
8065 C=.66:GOTO 8220
8070 IF NI=1 THEN C=.76:GOTO 8220
8080 C=.66:GOTO 8220
8100 IF EM=.9 THEN 8200
8110 IF NI=1 THEN C=.76:GOTO 8220
8120 C=.65:GOTO 8220
8200 IF NI=1 THEN C=.58:GOTO 8220
8210 C=.46:GOTO 8220
8220 PRINT"EM,NI,NG,C";EM,NI,NG,C
8221 GOTO 7500
8225 FOR J=1 TO 12
8230 F1=ATW*.8*EM*SF(J)*SS(J)
8240 QTW(J)=F1*C
8250 PRINT"QTW";QTW(J)
8260 NEXT J
8265 RETURN
9000 PRINT"ENTER AREA OF OPEN LOOP SOLAR COLL.":INPUT AC
9010 PRINT"ENTER TYPE OF ROOF:TYPE 1 FOR ORD,2 WHITE P.,3 AIR SPACE"
9020 PRINT"ENTER WALL/ROOF CODE:TYPE 1 FOR YEMEN,2 FOR INTERNATIONAL"
9040 PRINT"ENTER FLOW RATE":INPUT Q
9045 Z=Q/AC
9050 IF INT(Z)=20 THEN EFFC=.32:GOTO 9200
9060 IF INT(Z)=30 THEN EFFC=.38:GOTO 9200
9070 IF INT(Z)=40 THEN EFFC=.4:GOTO 9200
9080 IF INT(Z)=50 THEN EFFC=.44:GOTO 9200
9090 IF INT(Z)=60 THEN EFFC=.47:GOTO 9200
9100 IF INT(Z)=70 THEN EFFC=.49:GOTO 9200
9110 IF INT(Z)=80 THEN EFFC=.5:GOTO 9200
9200 PRINT"Z,EFFC";Z,EFFC
9205 GOTO 5000
9210 FOR J=1 TO 12
```

```
9220 QAC(J)=(.8499999*EFFC)*H(J)*AC*TF(J)
9230 PRINT"QAC=";QAC(J)
9240 NEXT J
9250 RETURN
9500 PRINT"IS THERE MASS WALL WITHIN THE SUNSPACE:TYPE 1 IF YES,0 IF NO"
9501 INPUT MS
9502 IF MS=0 THEN 9505
9503 PRINT"ENTER AREA,DIRECTION(1=E/W,2=N,3=S),CONST.NO.(INT FROM 1 TO 8)"
9504 INPUT AM,DR1,H
9505 PRINT"ENTER OVERALL TRANS.COEFF":INPUT TWA
9506 PRINT"IS THERE AN OPAQUE ROOF:TYPE 1 FOR YES,0 FOR NO":INPUT R1
9507 IF R1=0 THEN 9510
9508 PRINT"ENTER AREA,TYPE OF ROOF CONST(INT.FROM 1 TO 9)":INPUT AR,M
9509 HL=AR*UR(M)
9510 HL=0
9511 PRINT"IS THE SUN SPACE USED TO PREHEAT THE AIR:TYPE 1 FOR YES,0 NO"
9512 INPUT V1:PRINT"SPECIFY THE TYPE OF WALL CONST OF THE HOUSE(1 TO8)"
9513 PRINT"IS THE SUNSPACE COUPLED WITH HEAT EXCHANGER:TYPE 1 FOR YES,0 NO
9514 INPUT HE
9515 FOR J=1 TO 12:IF NCS=4 THEN A1=.7
9516 IF NCS=4 THEN A2=.89
9517 IF NCS=3 THEN A1=.67
9518 IF NCS=3 THEN A2=.8499999
9520 IF NCS=2 THEN A1=.87
9525 IF NCS=2 THEN A2=.87
9530 IF NCS=1 THEN A1=.9199999
9535 IF NCS=1 THEN A2=.9199999
9540 QS=(AGSE+AGSW)*SE(J)+AGSN*SN(J)+AGSS*SS(J)
9550 IF DR=1 THEN QSE=AGSH*SE(J)*SF(J)*.8499999*.8*.8
9560 IF DR=2 THEN QSE=AGSH*SN(J)*SF(J)*.8499999*.8*.8
9570 IF DR=3 THEN QSE=AGSH*SS(J)*SF(J)*.8499999*.8*.8
9575 IF MS=0 THEN 9590
9586 IF DR1=1 THEN QSUW=(.11*U(H)*ABW(H))*TWA*SE(J)*SF(J)*AM
9587 IF DR1=2 THEN QSUW=(.11*U(H)*ABW(H))*TWA*SN(J)*SF(J)*AM
9588 IF DR1=3 THEN QSUW=(.11*U(H)*ABW(H))*TWA*SS(J)*SF(J)*AM
9590 QS=(AGSE+AGSW)*SE(J)+AGSN*SN(J)+AGSS*SS(J):QS=SF(J)*QS
9595 FS=A1*QS-A2*QSE-QSUW
9650 LBM=(AGSE+AGSW+AGSN+AGSS)*4.3+90*.34+HL
9660 TSNG=(TA(J)*LBM+TT*LHD2(H))/(LBM+LHD2(H))
9670 TS=TSNG+FS/(.024*(LBM+LHD2(H))):TS(J)=TS
9675 QSB=LHD2(H)*(TS-TSNG)*.024
9690 IF HE=1 THEN QSA=.34*(TS-TSNG)*90*.024*.4:GOTO 9730
9700 QSA=.34*(TS-TSNG)*90*.024
9730 IF V1=1 THEN QST=QSE+QSUW+QSB+QSA:GOTO 9750
9740 QST=QSE+QSUW+QSB
9750 QST(J)=QST
9755 PRINT J;QSE;QSUW;QSB;QSA;QST;TS
9756 NEXT J
9760 GOTO 1442
10000 IF INT(X)>=7 THEN EFF=100
10010 IF INT(X)<=-5 THEN EFF=40
10020 IF INT(X)=-4 THEN EFF=47
10030 IF INT(X)=-3 THEN EFF=55
10040 IF INT(X)=-2 THEN EFF=62
10050 IF INT(X)=-1 THEN EFF=68
10060 IF INT(X)=0 THEN EFF=75
10070 IF INT(X)=1 THEN EFF=80
10080 IF INT(X)=2 THEN EFF=84
10090 IF INT(X)=3 THEN EFF=88
10100 IF INT(X)=4 THEN EFF=92
10110 IF INT(X)=5 THEN EFF=96
10120 IF INT(X)=6 THEN EFF=98
10130 RETURN
10500 IF INT(X)>=9 THEN EFF=100
10510 IF INT(X)<=-6 THEN EFF=23.5
10520 IF INT(X)=-5 THEN EFF=32
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10530 IF INT(X)=-4 THEN EFF=40
10540 IF INT(X)=-3 THEN EFF=48
10550 IF INT(X)=-2 THEN EFF=55
10560 IF INT(X)=-1 THEN EFF=62
10570 IF INT(X)=0 THEN EFF=67
10580 IF INT(X)=1 THEN EFF=75
10590 IF INT(X)=2 THEN EFF=78
10600 IF INT(X)=3 THEN EFF=84
10610 IF INT(X)=4 THEN EFF=88
10620 IF INT(X)=5 THEN EFF=92
10630 IF INT(X)=6 THEN EFF=94
10640 IF INT(X)=7 THEN EFF=96
10650 IF INT(X)=8 THEN EFF=99
10660 RETURN
```

```
10 DIM UW(8),FW(8),DW(8),ABW(8),LHD1(8),LHD2(8),CLB1(8),CLB2(8),ETA(8)
15 DIM UR(9),FR(9),DR(9),ABR(9),URA(9)
20 DIM H(12),SE(12),SN(12),SS(12),SNE(12),SSE(12),TA(12),N(12),SF(12)
25 DIM G(8,9)
30 DIM DD(12),DDC(12),QH(12),QC(12),QL(12),TT(12),QTH(12),QABW(12)
40 DIM FS(12),QABR(12),EEH(12),TNH(12),TI(12),QU(12),QAX(12),EFF(12)
50 DIM QST(12),TS(12),QT(12),QTW(12),QAC(12)
200 PRINT"ENTER CITY CODE:TYPE 0 FOR YEMEN; 1 FOR U.K. ;3 FOR GREECE"
210 INPUT CC
220 PRINT"ENTER RUN INDEX ACCORDINT TO THE FOLLOWING TABLE"
230 PRINT"RUN INDEX          OPTIONS                              "
235 PRINT"   1                MASSIVE WALLS+HORZ.ROOF              "
240 PRINT"   2                BUFFER(GARAGE)+CASE 1                "
245 PRINT"   3                BUFFER(SUNSPACE)+CASE1               "
250 PRINT"   4                TWO BUFFERS(GARAGE+SUNSPACE)+CASE1"
260 PRINT"   5                SUNSPACE COUPLED WITH AIRCOND.+CASE1"
265 PRINT"   6                OPEN LOOP SOLAR WALL+CASE1              "
270 PRINT"   7                TROMBE WALL+CASE1                       "
275 PRINT"   8                OPEN LOOP SOLAR COLL.INST.ON ROOF+CASE1"
280 PRINT"ENTER RUN INDEX":INPUT RI
530 FOR H=1 TO 8
540 READ UW(H),FW(H),DW(H),ABW(H),LHD1(H),LHD2(H),CLB1(H),CLB2(H)
550 DATA 1.47,0.05,0.52,0.4,12.5,18.7,0.94,0.89
560 DATA 1.29,0.07,0.42,0.6,11.0,17.3,0.94,0.90
570 DATA 3.36,0.06,0.45,0.65,26.3,32.5,0.87,0.81
580 DATA 0.72,0.04,0.62,0.64,6.30,12.5,0.97,0.92
590 DATA 5.34,0.45,0.17,0.65,38.7,44.5,0.80,0.74
600 DATA 2.89,0.28,0.22,0.64,23.1,29.3,0.88,0.83
610 DATA 2.93,0.14,0.32,0.4,23.2,29.6,0.88,0.83
620 DATA 5.19,0.17,0.29,0.4,37.9,43.7,0.81,0.75
630 NEXT H
631 FOR H=1 TO 8
632 READ ETA(H)
633 DATA 0.085,0.07,0.105,0.045,0.105,0.105,0.105,0.105
634 NEXT H
636 RA=1.06
640 FOR M=1 TO 9
650 READ UR(M),FR(M),DR(M),ABR(M)
660 DATA 2.26,0.45,0.15,0.6
670 DATA 2.10,0.45,0.15,0.6
680 DATA 1.83,0.50,0.13,0.6
690 DATA 2.11,0.42,0.14,0.65
700 DATA 2.72,0.45,0.15,0.65
710 DATA 10.32,0.45,0.15,0.65
720 DATA 7.72,0.27,0.22,0.65
730 DATA 2.86,0.19,0.28,0.65
740 DATA 2.30,0.10,0.36,0.65
745 URA(M)=UR(M)/(1+RA*UR(M))
750 NEXT M
760 FOR J=1 TO 12
770 READ H(J),SE(J),SN(J),SS(J),SNE(J),SSE(J),TA(J),N(J)
780 DATA 5.52,2.10,0.18,4.26,0.36,3.24,15.90,31
790 DATA 6.24,2.40,0.24,3.36,0.72,2.88,18.20,28
800 DATA 7.10,2.64,0.24,1.92,1.20,2.40,18.20,31
810 DATA 7.80,2.76,0.60,0.36,1.92,1.80,20.30,30
820 DATA 7.80,2.88,1.80,0.24,2.40,1.32,22.00,31
830 DATA 7.80,2.76,2.40,0.24,2.64,1.08,22.80,30
840 DATA 7.80,2.88,1.80,0.24,2.40,1.32,23.20,31
850 DATA 7.80,2.76,0.60,0.36,1.92,1.80,22.50,31
860 DATA 7.10,2.64,0.24,1.92,1.20,2.40,19.80,30
870 DATA 6.24,2.40,0.24,3.36,0.72,2.88,17.80,31
880 DATA 5.52,2.10,0.18,4.26,0.36,3.24,16.10,30
890 DATA 5.16,1.98,0.18,4.50,0.24,3.24,14.30,31
920 NEXT J
925 FOR J=1 TO 12
926 READ SF(J),TF(J)
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927 DATA 0.555,1.26,0.396,1.097,0.416,0.974,0.437,0.839,0.452,0.766,0.458
928 DATA 0.452,0.763,0.437,0.837,0.416,0.982,0.395,1.11,0.555,1.27,0.549
929 NEXT J
1370 IF RI=1 THEN GOSUB 5000
1380 IF RI=2 THEN GOSUB 5500
1390 IF RI=3 THEN GOSUB 6000
1395 IF RI=3 THEN 9500
1400 IF RI=4 THEN GOSUB 6500
1405 IF RI=4 THEN 9500
1410 IF RI=5 THEN GOSUB 7000
1415 IF RI=5 THEN 9500
1420 IF RI=6 THEN GOSUB 7500
1430 IF RI=7 THEN GOSUB 8000
1440 IF RI=8 THEN GOSUB 9000
1442 IF WC=2 THEN 1444
1443 PRINT"ENTER WALL,ROOF CONSTRUCTION NUMBER":INPUT H,M
1444 FOR J=1 TO 12
1445 IF J<=3 THEN TT=18:GOTO 1448
1446 IF J>=10 THEN TT=18:GOTO 1448
1447 TT=22
1448 DD(J)=(TT-TA(J))*N(J):DDC(J)=(TA(J)-TT)*N(J)
1449 IF DD(J)<0 THEN DD(J)=0
1450 IF DDC(J)<0 THEN DDC(J)=0
1451 QH(J)=.024*G(H,M)*V*DD(J)
1452 QC(J)=.024*G(H,M)*V*DDC(J)
1453 QL(J)=QC(J)+QH(J)
1454 TT(J)=TT:NEXT J:LPRINT"WALL CONSTRUCTION NUMBER=";H:LPRINT"ROOF CON
1455 PRINT"MONTH  EFF  TEMPERATURE IN (C)          ENERGY IN (KWH)
1456 PRINT"             TA    TT    TNH   TI     ENTRING    USEFUL   LOAD
1457 PRINT"                                       TO THE
1458 PRINT"                                       HOUSE
1459 LPRINT"MONTH  EFF  TEMPERATURE IN (C)          ENERGY IN (KWH)
1460 LPRINT"            TA    TT    TNH   TI      ENTERING  USEFUL    LOAD
1461 LPRINT"                                       TO THE
1462 LPRINT"                                       HOUSE
1463 IG=.13*AF
1470 FOR J=1 TO 12
1480 QDG=(AGE+AGW)*SE(J)+AGN*SN(J)+AGS*SS(J):QTH(J)=QDG*SF(J)
1486 IF WC=2 THEN UW=UW1:GOTO 1488
1487 UW=UW(H)
1488 IF WC=2 THEN ABW=.6:GOTO 1490
1489 ABW=ABW(H)
1490 IF WC=2 THEN FW=.45:GOTO 1495
1491 FW=FW(H)
1495 QABW=UW*ABW*FW*.22*((AWE+AWW)*SE(J)+AWN*SN(J)+AWS*SS(J))
1500 QABW(J)=QABW
1505 IF WC=2 THEN ABR=.6:GOTO 1525
1510 IF TR=2 THEN ABR=.3:GOTO 1525
1520 ABR=ABR(M)
1525 IF WC=2 THEN UR=UR1:GOTO 1550
1530 IF TR=3 THEN UR=URA(M):GOTO 1550
1540 UR=UR(M)
1550 IF WC=2 THEN  FR=.5:GOTO 1555
1551 FR=FR(H)
1555 QABR=UR*FR*ABR*.22*AF*H(J):QABR(J)=QABR
1570 QHH=QTH(J)+IG+QABW(J)+QABR(J)
1580 IF RI=1 THEN EEH=QHH:GOTO 1680
1590 IF RI=2 THEN EEH=QHH:GOTO 1680
1600 IF RI=3 THEN EEH=QHH+QST(J):GOTO 1680
1620 IF RI=4 THEN EEH=QHH+QST(J):GOTO 1680
1640 IF RI=5 THEN EEH=QHH+QST(J):GOTO 1680
1660 IF RI=6 THEN EEH=QHH+QT(J):GOTO 1680
1670 IF RI=7 THEN EEH=QHH+QTW(J)
1675 IF RI=8 THEN EEH=QTH(J)+IG+QABW(J)+(QABR(J)-AC*H(J)*TF(J))+QAC(J)
1680 EEH(J)=QHH
1690 TNH(J)=TA(J)+EEH(J)/(.024*V*G(H,M))
1691 X=TT(J)-TNH(J)
1692 IF H=1 THEN EFF=FXP(1.9+.966*LOG(X+14))-14:GOTO 1695
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1693 IF H=4 THEN EFF=EXP(1.9+.966*LOG(X+14))-14:GOTO 1695
1694 EFF=EXP(1.55+1.05*LOG(X+14))-14
1695 IF EFF>100 THEN EFF=100
1696 IF EFF<0 THEN EFF=0
1697 QU(J)=(EFF/100)*EEH(J)*N(J)
1698 IF QL(J)=0 THEN QAX(J)=0:GOTO 1700
1699 QAX(J)=QL(J)-QU(J)
1700 IF QL(J)=0 THEN TI(J)=TNH(J):GOTO 1710
1705 TI(J)=TA(J)+EEH(J)/(.024*G(H,M)*V)+(QAX(J)/QL(J))*(TT(J)-TA(J))
1710 EFF(J)=EFF
1715 PRINT J;TAB(5);INT(EFF(J));TAB(10);INT(TA(J));TAB(15);INT(TT(J));
1716 PRINT INT(TNH(J));TAB(25);INT(TI(J));TAB(35);INT(EEH(J)*N(J));TAB(45
1717 PRINT INT(QU(J));TAB(55);INT(QL(J));TAB(65);INT(QAX(J))
1718 LPRINT J;TAB(5);INT(EFF(J));TAB(10);INT(TA(J));TAB(15);INT(TT(J));
1719 LPRINT INT(TNH(J));TAB(25);INT(TI(J));TAB(35);INT(EEH(J)*N(J));
1720 LPRINT INT (QU(J));TAB(55);INT(QL(J));TAB(65);INT(QAX(J));
1721 LPRINT
1722 NEXT J
1723 LPRINT"-----------------------------------------------------------------
"
1725 PRINT"WOULD LIKE A PRINT OUT:TYPE 1 FOR YES,0 FOR NO":INPUT PI
1726 IF PI=0 THEN 2610
1730 LPRINT"RUN INDEX                         TYPE OF ROOF"
1735 LPRINT RI;TAB(45);TR
1737 LPRINT:LPRINT:LPRINT:LPRINT
1738 LPRINT"       DESIGN CHARACTERISTICS OF THE CONSIDERED CASE
1739 LPRINT"      SOLID  WALL AREA            GLAZED    AREA      ROOF AREA
1740 LPRINT"EAST   WEST  NORTH SOUTH   EAST  WEST  NORTH SOUTH
1741 LPRINT
1742 LPRINT AWE;TAB(10);AWW;TAB(20);AWN;TAB(30);AWS;TAB(40);AGE;
1743 LPRINT TAB(60);AGN;TAB(65);AGS;TAB(70);AF;TAB(75);V
1756 LPRINT"TABLE2:EFFECT OF WALL/ROOF INSULATION AND PASSIVE FEATURES ON
1757 LPRINT"                 HEATING/COOLING LOADS OF THE HOUSE
1760 LPRINT"WALL ROOF MONTH DEGREE-DAYS  AMBIENT       LOAD IN (KWH)       "
1770 LPRINT"TYPE TYPE       HEATING COOL AIR TEMP.   HEATING COOLING TOT"
1780 LPRINT"-----------------------------------------------------------------"
1790 LPRINT
1800 LPRINT H;
1820 LPRINT TAB(5);M;
1830 FOR J=1 TO 12
1840 LPRINT TAB(10);J;TAB(15);DD(J);TAB(25);DDC(J);TAB(35);TA(J);TAB(45);
1850 LPRINT QH(J);TAB(55);QC(J);TAB(65);QL(J);
1855 DDT=DDT+DD(J):DDCT=DDCT+DDC(J):QHT=QHT+QH(J):QCT=QCT+QC(J):QLT=QLT+Q
1856 QLT=QLT+QL(J)
1860 LPRINT
1870 NEXT J
1880 LPRINT"-----------------------------------------------------------------"
1900 LPRINT TAB(15);DDT;TAB(25);DDCT;TAB(45);QHT;TAB(55);QCT;TAB(65);
1910 LPRINT:LPRINT:LPRINT:LPRINT
1920 LPRINT"TABLE3:EFFECT OF WALL-ROOF COUPLING ON HEAT GAINS

1930 LPRINT"WALL ROOF MONTH        ENERGY GAINS IN (KWH/DAY)
1940 LPRINT"TYPE TYPE              TRANSMITTED    ABSORBED
1950 LPRINT"                       VIA WINDOWS  WALL  ROOF                  "
1960 LPRINT"-----------------------------------------------------------------
1970 LPRINT
1990 LPRINT H;
2010 LPRINT TAB(5);M;
2020 FOR J=1 TO 12
2030 LPRINT TAB(10);J;TAB(15);QTH(J);TAB(30);QABW(J);TAB(45);QABR(J);
2040 LPRINT TAB(60);EEH(J);
2045 TEEH=TEEH+EEH(J)
2050 LPRINT
2060 NEXT J
2065 LPRINT"-----------------------------------------------------------------"
2100 LPRINT TAB(60);TEEH
2110 LPRINT:LPRINT:LPRINT:LPRINT
```

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2120 LPRINT"TABLE5:EFFECT OF WALL-ROOF COUPLING ON THE USEFUL ENERGY GAINS
2130 LPRINT"WALL ROOF MONTH    ENERGY        USEFUL       AUX
2140 LPRINT"TYPE TYPE          ENTERED       GAIN                          "
2150 LPRINT"              TO THE HOUSE
2160 LPRINT"                 ( KWHR  )   (KWHR)                    (KWHR)
2170 LPRINT"------------------------------------------------------------------
2185 LPRINT H;
2190 LPRINT TAB(5);M;
2200 FOR J=1 TO 12
2210 LPRINT TAB(10);J;TAB(15);EEH(J)*N(J);TAB(30);QU(J);TAB(45);
2220 LPRINT QAX(J)
2225 IF QAX(J)<0 THEN QAX(J)=ABS(QAX(J))
2226 TQU=TQU+QU(J):TAX=TAX+QAX(J)
2230 LPRINT
2240 NEXT J
2250 LPRINT"------------------------------------------------------------------
2255 LPRINT TAB(30);TQU;TAB(45);TAX
2290 LPRINT:LPRINT:LPRINT:LPRINT:LPRINT
2300 LPRINT"TABLE4:EFFECE OF WALL-ROOF COUPLING ON THE EFF AND INSIDE TEMP
2310 LPRINT"WALL ROOF MONTH  EFFICIENCY INSIDE HOUSE TEMP.  TEMP.INCREASE"
2320 LPRINT"                                  ( C )               ( C )    "
2325 LPRINT"                          WITHOUT AX    WITH AX                "
2330 LPRINT"------------------------------------------------------------------
2340 LPRINT
2360 LPRINT H;
2380 LPRINT TAB(5);M;
2390 FOR J=1 TO 12
2400 LPRINT TAB(10);J;TAB(15);EFF(J);TAB(25);TA(J);TAB(35);TNH(J);TAB(45);
2405 IF QL(J)=0 THEN DELT=EEH(J)/(.024*G(H,M)*V):GOTO 2420
2410 DELT=EEH(J)/(.024*G(H,M)*V)+(QAX(J)/QL(J))*(TT(J)-TA(J))
2420 LPRINT TI(J);TAB(55);TT(J);TAB(65);DELT
2430 LPRINT
2435 TNHT=TNHT+TNH(J):TIT=TIT+TI(J):DELTT=DELTT+DELT:EFFT=EFFT+EFF(J)
2440 NEXT J
2450 LPRINT"------------------------------------------------------------------
2455 LPRINT TAB(20);EFFT/12;TAB(40);TNHT/12;TAB(50);TIT/12;TAB(60);DELTT/1
2456 DDT=0:DDCT=0:QHT=0:QCT=0:QLT=0:TEEH=0:TQU=0:TAX=0:TNHT=0:TIT=0:DELTT=
2457 EFFT=0
2490 FOR J=1 TO 12
2500 QTH(J)=0:QABW(J)=0:QABR(J)=0:EEH(J)=0:TNH(J)=0:QU(J)=0
2510 QAX(J)=0:EFF(J)=0:TI(J)=0
2550 NEXT J
2610 IF H>1 THEN 2655
2611 IF M>1 THEN 2655
2612 FOR H=1 TO 8
2613 IF PI=0 THEN 2620
2615 LPRINT H;
2620 FOR M=1 TO 9
2625 IF PI=0 THEN 2650
2630 LPRINT TAB(10);1/UW(H);TAB(30);1/UR(M);TAB(45);G(H,M);
2635 LPRINT
2640 NEXT M
2650 NEXT H
2655 PRINT"WOULD YOU LIKE TO CHANGE WALL/ROOF CONST.MAT.FOR THE SAME OPT.
2656 PRINT"ENTER 1 IF YES 0 IF NO":INPUT RR
2657 IF RR=1 THEN 1442
2660 PRINT"WOULD YOU LIKE ANOTHER OPTION:TYPE 1 FOR YES,0 FOR NO"
2670 INPUT RII
2680 IF RII=1 THEN 2691
2690 END
2691 FOR H=1 TO 8
2692 FOR M=1 TO 9
2693 G(H,M)=0
2694 NEXT M
2695 NEXT H
```

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2700 PRINT"RUN INDEX        OPTIONS"
2710 PRINT"    1            HOUSE  "
2720 PRINT"    2            HOUSE +GARAGE"
2730 PRINT"    3            HOUSE+SUNSPACE"
2740 PRINT"    4            HOUSE+GARAGE+SUNSPACE"
2750 PRINT"    5            HOUSE+SUNSPACE COUPLED WITH AIR EXCHANGER"
2760 PRINT"    6            OPEN LOOP SOLAR WALL INST.ON THE SOUTH+HOUSE"
2770 PRINT"    7            TROMBE WALL          ======================"
2780 PRINT"    8            OPEN LOOP SOLAR COLLECTOR INST ON ROOF+HOUSE"
2790 INPUT RI:GOTO 1370
5000 AW=90:AG=6.24:AF=48:AD=2.1:LF=7.58:V=167.503
5010 AWE=21.4:AWW=20.7:AWN=24.4:AWS=23.3
5020 AGE=1.2:AGW=1.92:AGN=0:AGS=3.12
5025 PRINT"ENTER TYPE OF ROOF:1 ORDINARY,2 WITH WHITE TILE,3 WITH AIR SPA"

5030 PRINT"ENTER WALL/ROOF CODE:1 FOR YEMENI WALLS/ROOFS,2 INTERNATIONAL"

5035 IF WC=1 THEN 5045
5036 PRINT"ENTER UWALL,UROOF,AND UWINDOW":INPUT UW1,UR1,UWIN
5037 G1=AW*UW1+AF*UR1+AG*UWIN+3.33*AD+2.1*LF+.34*V
5038 IF RI=8 THEN G1=G1-.34*EFFC*Q

5039 G1=G1/V
5040 GOTO 5140
5045 FOR H=1 TO 8
5050 FOR M=1 TO 9
5060 IF TR=3 THEN UR=URA(M):GOTO 5075
5070 UR=UR(M)
5075 X2=.34*EFFC*Q
5080 G=AW*UW(H)+AF*UR+AG*4.3+AD*3.33+2.1*LF+.34*V
5085 IF RI=8 THEN G=G-X2
5090 G(H,M)=G/V
5120 NEXT M
5130 NEXT H
5135 IF RI=8 THEN 9210
5136 PRINT"ENTER PRINT INDEX:TYPE 1 TO PRINTER,0 OTHERWISE"
5137 INPUT PI
5138 IF PI=0 THEN 5210
5140 LPRINT" TABLE( ):CHARACTERISTICS OF THE INPUTTED HOUSE"
5145 LPRINT"SOLID WALL AREA IN(SQ.M.):  EAST    WEST  NORTH   SOUTH "
5150 LPRINT TAB(20);AWE;TAB(30);AWW;TAB(40);AWN;TAB(50);AWS;TAB(60);AW
5160 LPRINT
5170 LPRINT"WWINDOW AREA IN(SQ.M.)    :                                  "
5175 LPRINT TAB(20);AGE;TAB(30);AGW;TAB(40);AGN;TAB(50);AGS;TAB(60);AG
5180 LPRINT"ROFF AREA          VOLUME              G_FACTOR"
5185 LPRINT"(SQ.M.)            (CUBIC M)           (W/CMC)  "
5190 LPRINT AF;TAB(35);V;TAB(55);G1
5195 LPRINT:LPRINT:LPRINT
5200 LPRINT"----------------------------------------------------------
5210 RETURN
5500 AW=80.75:AG=6.24:AF=48.13301:AD=2.1:LF=7.6:V=167.503
5510 AWE=21.4:AWW=20.7:AWN=12.2:AWS=23.3
5520 AGE=1.2:AGW=1.92:AGN=0:AGS=3.12
5525 PRINT"ENTER TYPE OF ROOF:1 ORDINARY,2WITH WHITE PAINT,3 WITH AIR SPA

5530 PRINT"ENTER WALL/ROOF CODE:1 FOR YEMENI WALLS/ROOFS,2 INTERNATIONAL"

5540 IF WC=2 THEN PRINT"ENTER UWALL,UROOF,UWIN":INPUT UW1,UR1,UWIN
5550 FOR H=1 TO 8
5560 FOR M=1 TO 9
5570 IF TR=3 THEN UR=URA(M):GOTO 5585
5580 UR=UR(M)
5585 X1=1-CLB1(H)
5590 G=UW(H)*AW+UR*AF+4.3*AG+3.33*AD+2.1*LF+.34*(V-X1*30)+LHD1(H)
5595 G=G/V:G(H,M)=G
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5598 NEXT M
5599 NEXT H:GOTO 5695
5600 G1=UW1*AW+UR1*AF+UWIN*AG+2.1*LF+3.33*AD+.34*(V-CLB1(8)*30)+LHD1(8)
5610 G1=G1/V
5695 RETURN
6000 PRINT"ENTER TYPE OF BUFFER:TYPE 1 FOR NON-TRANS,2 FOR TRANS.PARENT"
6010 PRINT"ENTER TYPE OF ROOF:1 ORDIN,2WHITE PAINT,3 AIR SPACE":INPUT TR
6020 PRINT"ENTER WALL/ROOF CODE:1 FOR YEMENIS,2 INTEERNATIONAL":INPUT WC
6030 PRINT"ENTER DIRECTION OF THE WINDOW BETWEEN HEATED AND SUNSPACE"
6035 PRINT" TYPE 1 FOR EAST/WEST DIRECTIONS,2 FOR NORTH,3 FOR SOUTH"
6040 AW=79.75:AG=4.8:AD=2.1:AF=48.13301:V=167.503:LF=7.6
6045 AWE=21.4:AWW=20.7:AWN=24.4:AWS=13.28
6050 AGE=1.2:AGW=1.92:AGN=0:AGS=1.68
6055 PRINT"ENTER NUMBER OF COLLECTING SURFACES":INPUT NCS
6056 PRINT"ENTER AREA OF THE COLLECTING SURFACES IN THE FOLLOWING ORDER"
6057 PRINT"EAST,WEST,NORTH,AND SOUTH":INPUT AGSE,AGSW,AGSN,AGSS
6058 PRINT"ENTER AREA OF THE WINDOW BETWEEN SUNSPACE,AND HEATED SPACE"
6059 INPUT AGSH
6060 IF WC=1 THEN 6100
6065 PRINT"ENTER UW,UROOF,UWIN":INPUT UW1,UR1,UWIN
6070 IF RI=5 THEN X1=.34*V(1-.4*(90/V)-.4*(1-CLB2(8))*(90/V)):GOTO 6080
6075 X1=.34*V*(1-(90/V)*(1-CLB2(8)))
6080 G1=UW1*AW+UR1*AF+UWIN*AG+3.33*AD+2.1*LF+X1
6090 G1=G1/V:GOTO 6200
6100 FOR H=1 TO 8
6120 FOR M=1 TO 9
6130 IF TR=3 THEN UR=URA(M):GOTO 6150
6140 UR=UR(M)
6150 IF RI=5 THEN X1=.34*V*(1-.4*(90/V)-.4*(1-CLB2(H))*(90/V)):GOTO 6170
6160 X1=.34*V*(1-(90/V)*(1-CLB2(H)))
6170 G=UW(H)*AW+UR*AF+3.33*AD+4.3*AG+2.1*LF+X1
6180 G=G/V:G(H,M)=G
6195 NEXT M
6196 NEXT H
6285 IF RI=5 THEN 7010
6290 RETURN
6500 AW=70.7:AG=4.8:AD=2.1:LF=7.6:V=167.503:AF=48
6510 AWE=21.4:AWW=20.7:AWN=15.3
6520 AGE=1.2:AGW=1.92:AGN=0:AGS=1.68
6525 AWS=7.6*3.48-AGS-AGSS
6530 PRINT"ENTER NO.OF COLLECTING SURFACES":INPUT NCS
6531 PRINT"ENTER AREA OF THE COLLECTING SUR.IN EAST,WEST,NORTH,AND SOUTH"
6532 INPUT AGSE,AGSW,AGSN,AGSS
6533 PRINT"ENTER DIRECTION OF THE WINDOW BETWEEN SUNSPACE AND H.SPACE"
6534 PRINT"TYPE 1=E/W,2=N,3=S":INPUT DR
6535 PRINT"AREA OF THE WINDOW":INPUT AGSH
6540 PRINT"ENTER ROOF TYPE:1 ORDIN,2 WITH WP,3 WITH A.S.":INPUT TR
6550 PRINT"ENTER TYPE OF SUNSPACE:1 NONTRANS,2TRANS":INPUT TB
6560 PRINT"ENTER DIRECTION OF WINDOW BETWEEN S.S AND H.S.":INPUT DR
6570 PRINT"ENTER ROOF CODE:1 YEMENI,2 INTERNATIONA":INPUT WC
6580 IF WC=1 THEN 6640
6590 X1=.34*V*(1-(30/V)*(1-CLB1(8))-(90/V)*(1-CLB2(8)))
6600 PRINT"ENTER UWALL,UROOF,UWIN":INPUT UW1,UR1,UWIN
6610 G1=UW1*AW+UR11*AF+3.33*AD+UWIN*AG+2.1*LF+LHD1(8)+LHD2(8)+X1
6620 G1=G1/V
6630 GOTO 6800
6640 FOR H=1 TO 8
6660 FOR M=1 TO 9
6670 IF TR=3 THEN UR=URA(M):GOTO 6685
6680 UR=UR(M)
6685 X1=.34*V(1-(30/V)*(1-CLB1(H))-(90/V)*(1-CLB2(H)))
6690 G=UW(H)*AW+UR*AF+3.33*AD+2.1*LF+4.3*AG+X1+LHD1(H)+LHD2(H)
6700 G=G/V:G(H,M)=G
6730 NEXT M
6740 NEXT H
6820 RETURN
```

```
7000 TF RI=5 THEN 6000
7010 RETURN
7500 AW=78.4:AG=6.24:AF=48.13301:AD=2.1:V=167.503:LF=7.6
7510 AWE=20.7:AWW=20.22:AWN=24.35
7520 AGE=1.92:AGW=2.4:AGN=0:AGS=1.92
7525 IF RI=7 THEN 7540
7530 PRINT"ENTER AREA OF O.L.S.W.":INPUT ASW:QSW=10*ASW
7535 AWS=7.6*3.48-AGS-ASW
7540 PRINT"ENTER TYPE OF ROOF,1 ORDINARY,2 WHITE P.,3 A.S":INPUT TR
7545 PRINT"ENTER WALL/ROOF CODE,1 FOR YEMENI,2 INTERNATIONAL":INPUT WC
7550 IF WC=1 THEN 7600
7555 PRINT"ENTER UW,UR,UWIN":INPUT UW1,UR1,UWIN
7560 G1=UW1*AW+UR1*AF+UWIN*AG+3.33*AD+2.1*LF+.34*V*(1-(QSW/V)*ETA(8))
7565 G1=G1/V
7570 LPRINT"VOLUME                    ROOF AREA        G-FACTOR"
7575 LPRINT V;TAB(30);AF;TAB(40);G1
7580 LPRINT"------------------------------------------------------------"
7590 GOTO 7665
7600 FOR H=1 TO 8
7615 FOR M=1 TO 9
7620 IF TR=3 THEN UR=URA(M):GOTO 7630
7625 UR=UR(M)
7630 G=UW(H)*AW+UR*AF+4.3*AG+3.33*AD+2.1*LF+.34*V*(1-(QSW/V)*ETA(H))
7640 G(H,M)=G/V
7655 NEXT M
7660 NEXT H
7665 IF RI=7 THEN 8225
7666 PRINT"SPECIFY THE CONST.MATERIAL OF THE OPEN LOOP SOLAR WALL(1 TO 8)
7667 INPUT H
7670 ABW=ABW(H)
7680 FOR J=1 TO 12
7690 F=ASW*ABW*.8*SS(J)
7695 IF WC=1 THEN 7710
7700 ETA=ETA(8):X1=(1+.11*UW1)/(UW1*ASW):GOTO 7750
7710 ETA=ETA(H):X1=(1+.11*UW(H))/(UW(H)*ASW)
7750 QASW=.34*QSW*ETA*F*.9*X1
7760 IF WC=2 THEN UW=UW1:GOTO 7780
7770 UW=UW(H)
7780 QWSW=F*UW*.22*.9
7790 QT(J)=QASW+QWSW:PRINT"QT=";QT(J)
7795 NEXT J
7800 RETURN
8000 PRINT"ENTER AREA OF TRMBE WALL":INPUT ATW
8010 PRINT"SPECIFY THE EMISSIVITY OF THE ABSORBER(0.1 OR 0.9)":INPUT EM
8020 PRINT"SPECIFY THE NATURE OF GLAZING:1 SINGLE,2 DOUBLE":INPUT NG
8030 PRINT"IS THERE AN INSULATTING SHUTTER AT NIGHT(1 YES,0 NO)":INPUT NI
8040 IF NG=1 THEN 8100
8050 IF EM=.9 THEN 8070
8060 IF NI=1 THEN C=.8499999:GOTO 8220
8065 C=.66:GOTO 8220
8070 IF NI=1 THEN C=.76:GOTO 8220
8080 C=.66:GOTO 8220
8100 IF EM=.9 THEN 8200
8110 IF NI=1 THEN C=.76:GOTO 8220
8120 C=.65:GOTO 8220
8200 IF NI=1 THEN C=.58:GOTO 8220
8210 C=.46:GOTO 8220
8220 PRINT"EM,NI,NG,C";EM,NI,NG,C
8221 GOTO 7500
8225 FOR J=1 TO 12
8230 F1=ATW*.8*EM*SF(J)*SS(J)
8240 QTW(J)=F1*C
8250 PRINT"QTW";QTW(J)
8260 NEXT J
8265 RETURN
9000 PRINT"ENTER AREA OF OPEN LOOP SOLAR COLL.":INPUT AC
9010 PRINT"ENTER TYPE OF ROOF:TYPE 1 FOR ORD.2 WHITE P.,3 AIR SPACE"
```

```
9020 PRINT"ENTER WALL/ROOF CODE:TYPE 1 FOR YEMEN,2 FOR INTERNATIONAL"
9040 PRINT"ENTER FLOW RATE":INPUT Q
9045 Z=Q/AC
9050 IF INT(Z)=20 THEN EFFC=.32:GOTO 9200
9060 IF INT(Z)=30 THEN EFFC=.38:GOTO 9200
9070 IF INT(Z)=40 THEN EFFC=.4:GOTO 9200
9080 IF INT(Z)=50 THEN EFFC=.44:GOTO 9200
9090 IF INT(Z)=60 THEN EFFC=.47:GOTO 9200
9100 IF INT(Z)=70 THEN EFFC=.49:GOTO 9200
9110 IF INT(Z)=80 THEN EFFC=.5:GOTO 9200
9200 PRINT"Z,EFFC";Z,EFFC
9205 GOTO 5000
9210 FOR J=1 TO 12
9220 QAC(J)=(.8499999*EFFC)*H(J)*AC*TF(J)
9230 PRINT"QAC=";QAC(J)
9240 NEXT J
9250 RETURN
9500 PRINT"IS THERE MASS WALL WITHIN THE SUNSPACE:TYPE 1 IF YES,0 IF NO"
9501 INPUT MS
9502 IF MS=0 THEN 9505
9503 PRINT"ENTER AREA,DIRECTION(1=E/W,2=N,3=S),CONST.NO.(INT FROM 1 TO 8)
9504 INPUT AM,DR1,H
9505 PRINT"ENTER OVERALL TRANS.COEFF":INPUT THA
9506 PRINT"IS THERE AN OPAQUE ROOF:TYPE 1 FOR YES,0 FOR NO":INPUT R1
9507 IF R1=0 THEN 9510
9508 PRINT"ENTER AREA,TYPE OF ROOF CONST(INT.FROM 1 TO 9)":INPUT AR,M
9509 HL=AR*UR(M)
9510 HL=0
9511 PRINT"IS THE SUN SPACE USED TO PREHEAT THE AIR:TYPE 1 FOR YES,0 NO"
9512 INPUT V1:PRINT"SPECIFY THE TYPE OF WALL CONST OF THE HOUSE(1 TO8)"
9513 PRINT"IS THE SUNSPACE COUPLED WITH HEAT EXCHANGER:TYPE 1 FOR YES"
9514 INPUT HE
9515 FOR J=1 TO 12:IF NCS=4 THEN A1=.7
9516 IF NCS=4 THEN A2=.89
9517 IF NCS=3 THEN A1=.67
9518 IF NCS=3 THEN A2=.8499999
9520 IF NCS=2 THEN A1=.87
9525 IF NCS=2 THEN A2=.87
9530 IF NCS=1 THEN A1=.9199999
9535 IF NCS=1 THEN A2=.9199999
9540 QS=(AGSE+AGSW)*SE(J)+AGSN*SN(J)+AGSS*SS(J)
9550 IF DR=1 THEN QSE=AGSH*SE(J)*SF(J)*.8499999*.8*.8
9560 IF DR=2 THEN QSE=AGSH*SN(J)*SF(J)*.8499999*.8*.8
9570 IF DR=3 THEN QSE=AGSH*SS(J)*SF(J)*.8499999*.8*.8
9575 IF MS=0 THEN 9590
9586 IF DR1=1 THEN QSUW=(.11*U(H)*ABW(H))*THA*SE(J)*SF(J)*AM
9587 IF DR1=2 THEN QSUW=(.11*U(H)*ABW(H))*THA*SN(J)*SF(J)*AM
9588 IF DR1=3 THEN QSUW=(.11*U(H)*ABW(H))*THA*SS(J)*SF(J)*AM
9590 QS=(AGSE+AGSW)*SE(J)+AGSN*SN(J)+AGSS*SS(J):QS=SF(J)*QS
9595 FS=A1*QS-A2*QSE-QSUW
9650 LBM=(AGSE+AGSW+AGSN+AGSS)*4.3+90*.34+HL
9660 TSNG=(TA(J)*LBM+TT*LHD2(H))/(LBM+LHD2(H))
9670 TS=TSNG+FS/(.024*(LBM+LHD2(H))):TS(J)=TS
9675 QSB=LHD2(H)*(TS-TSNG)*.024
9690 IF HE=1 THEN QSA=.34*(TS-TSNG)*90*.024*.4:GOTO 9730
9700 QSA=.34*(TS-TSNG)*90*.024
9730 IF V1=1 THEN QST=QSE+QSUW+QSB+QSA:GOTO 9750
9740 QST=QSE+QSUW+QSB
9750 QST(J)=QST
9755 PRINT J;QSE;QSUW;QSB;QSA;QST;TS
9756 NEXT J
9760 GOTO 1442
```

DIRECT-GAIN AND TROMBE WALL COMPUTER SIMULATION PROGRAM

```
10 DIM N1(12),TA(12),DD(12),N(12),H(12),H0(12),KT(12),DEC(12),W(12),DL(12)
20 DIM RB(12),UW(8),UR(9),RDH(12),R(12),RBN(12),RDN(12),RTN(12),RDHN(12)
30 DIM R1(12),HT(12),A(12),B(12),C(12)
35 DIM DDR(12),DDB(12),DDB1(12),LA1(12),LA(12),LW(12),TW(12),QIS(12),
I(12)
40 DIM QXDI(12),ICD(12),ICS(12),XCD(12),XCS(12),PD(12),PS(12),QDD(12)
41 DIM QXSZ(12),QXDZ(12),FID(12),FIS(12),XD(12),XS(12),FZD(12),FZS(12)
42 DIM YS(12),FD(12),FS(12),QXD(12),QXS(12),ETAD(12),ETAS(12),TNHD(12)
43 DIM DELT1(12),DELT2(12)
50 FOR J=1 TO 12
60 READ N1(J),TA(J)
70 DATA 31,15.9,28,18.2,31,18.2,30,20.3,31,22,30,22.8,31,23.2,31,22.5
75 DATA 30,19.8,31,17.8,30,16.1,31,14.3
80 NEXT J
100 FOR J=1 TO 12
110 READ N(J),H(J),H0(J)
120 DATA 21,18.7,28.93,49,20.9,32.31,80,22.7,35.43,110,24.1,37.67,141,24.8
130 DATA 171,24.8,38.1,202,24.8,37.98,233,24.8,37.69,264,23.8,36.14,295,21
140 DATA 325,19.8,29.67,355,18.4,27.93
150 NEXT J
151 FOR H=1 TO 8
152 READ UW(H)
153 DATA 1.47,1.29,3.36,0.72,5.34,2.89,2.93,5.19
154 NEXT H
155 FOR M=1 TO 9
156 READ UR(M)
157 DATA 2.26,2.1,1.83,2.11,2.72,10.32,7.72,2.86,2.3
158 NEXT M
160 L=(3.142/180)*15:COSL=COS(L):SINL=SIN(L):TANL=TAN(L)
170 FOR J=1 TO 12
180 KT(J)=H(J)/H0(J)
190 DEC=(23.45)*SIN((3.142/180)*(360/365)*(N(J)+284)):DEC(J)=DEC
200 DEC1=(3.142/180)*DEC:COSD=COS(DEC1):SIND=SIN(DEC1):TAND=TAN(DEC1)
210 X1=-TAND*TANL:X2=-ATN(X1/SQR(1-X1*X1))+1.5708:W(J)=(180/3.142)*X2
220 DL(J)=(180/3.142)*(2/15)*X2
230 FOR Y=1 TO 13
240 HA=(3.142/180)*15*((5+Y)-12):COSH=COS(HA):SINH=SIN(HA)
250 X3=COSD*COSL*COSH+SINH*SIND
260 SAL=ATN(X3/SQR(1-X3*X3))
270 X4=-COSD*(SINH/COS(SAL))
275 IF X4*X4>1 THEN 290
280 SAZ=ATN(X4/SQR(1-X4*X4))
290 IF SIN(SAL)=0 THEN 310
300 R=COS(SAL)*(COS(SAZ)/SIN(SAL))
310 IF R<0 THEN R=0
320 IF R>3 THEN R=3
325 PRINT Y+5,SAL*(180/3.142),SAZ*(180/3.142),DEC(J),R
330 RT=RT+R
340 NEXT Y
350 RB(J)=RT/DL(J):PRINT"RB";RB(J)
360 RDH(J)=1.39-4.03*KT(J)+5.53*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)
370 R(J)=(1-RDH(J))*RB(J)+RDH(J)
375 PRINT"RT=";R(J)
380 RDHN(J)=1.0045+.04349*KT(J)-3.5227*KT(J)*KT(J)+2.63*KT(J)*KT(J)*KT(J)
390 RDN(J)=(3.142/24)*((1-COS(X2))/(SIN(X2)-(3.142/180)*W(J)*COS(X2)))
400 RTN(J)=RDN(J)*(1.07+.025*SIN(X2-3.142/3))
410 X5=COSD*COSL+SIND*SINL
420 SALN=ATN(X5/SQR(1-X5*X5))
430 RBN(J)=COS(SALN)/SIN(SALN)
440 RN(J)=(1-(RDN(J)/RTN(J))*RDHN(J))*RBN(J)+(RDN(J)/RTN(J))*RDHN(J)
```

```
450 R1(J)=R(J)/RN(J)
460 HT(J)=R(J)*H(J)
461 A(J)=2.943-9.271*KT(J)+4.031*KT(J)*KT(J)
462 B(J)=-4.345+8.853001*KT(J)-3.602*KT(J)*KT(J)
463 C(J)=-.17-.306*KT(J)+2.936*KT(J)*KT(J)
480 RT=0
490 NEXT J
495 PRINT"ENTER PRINTING INDEX,1 TO PRINTER 0 TO SCREEN":INPUT PI
496 IF PI=0 THEN 755
500 LPRINT"TABLE1:SOLAR RADIATION FALLING ON THE TILTED AND HORIZONTAL"
510 LPRINT"      SURFACES OF A HOUSE IN THE YEMEN EVALUATED ON 21ST.DAY"
520 LPRINT"MONTH  SOLAR RADIATION IN(MJ/M-DAY) CLEARNESS FACTOR         "
530 LPRINT"       EXT.  HORIZONTAL  VERTICAL                            "
540 LPRINT"-------------------------------------------------------------"
550 LPRINT
560 FOR J=1 TO 12
570 LPRINT J;TAB(10);H0(J);TAB(20);H(J);TAB(25);HT(J);TAB(45);KT(J);
580 LPRINT
590 NEXT J
600 LPRINT:LPRINT:LPRINT:LPRINT
610 LPRINT"TABLE2:COMPONENT OF SOLAR RADIATION AS EVALUATED ON THE 21ST
620 LPRINT"MONTH    DIFFUSE      DIRECT        GLOBAL
630 LPRINT"-----------------------------------------------------------------
640 LPRINT
650 FOR J=1 TO 12
660 LPRINT J;TAB(10);RDH(J);TAB(30);RB(J);TAB(55);R(J)
670 NEXT J
680 LPRINT:LPRINT:LPRINT
690 LPRINT"TABLE3:COMPONENT OF SOLAR RADIATION AS EVALUATED ON"
700 LPRINT"                    OF THE 21ST DAY OF THE MONTH
710 LPRINT
720 FOR J=1 TO 12
730 LPRINT J;TAB(10);RBN(J);TAB(20);RN(J);TAB(30);RDN(J);TAB(40);RTN(J)
740 LPRINT RDHN(J);TAB(60);R1(J)
750 NEXT J
755 PRINT"ENTER FLOOR AREA(220 SQ.M.)":INPUT AF
756 PRINT"ENTER THERMOSTAT SET TEMPERATURE":INPUT TE
760 PRINT"INPUT THICKNESS AND THERMAL CONDUCTIVITY OF THE STORAGE WALL"
770 PRINT"ENTER IN METER AND (W/MC) RESPECTIVELY":INPUT D1,K1
780 PRINT"ENTER DENSITY(KG/CUBE METER),SPECIFIC HEAT IN(J/KG C)":INPUT RO
790 PRINT"ENTER AREA OF THE STORAGE WALL IN(SQ.M.)":INPUT AW
820 PRINT"SPECIFY TYPE OF EXTERNAL HOUSE WALL(INT.FROM 1 TO 8)":INPUT H
825 PRINT"SPECIFY THE TYPE OF ROOF(INT FROM 1 TO9)":INPUT M
826 PRINT"ENTER GLAZED AREA":INPUT AG
830 UA1=AF*UW(H)+4.3*AG
840 UW=(1/((1/3.7)+(1/8.3)+(D1/K1)))
845 UA=AF*UW(H)
850 NS=.024*3.6
860 UK=(8.3*K1)/(K1+D1*8.3)
870 DELT=(.13*AF*3.6)/(UA*.024*3.6):DELTD=(.13*AF*3.6)/(UA1*.024*3.6)
875 TB=TE-DELT:TBD=TE-DELTD
880 FOR J=1 TO 12
900 DDR=N1(J)*(TE-TA(J))
905 IF DDR<=0 THEN DDR=0
910 LA=DDR*UA*.024*3.6:LA1=DDR*UA1*.024*3.6
920 LW=DDR*UW*AW*.024*3.6
930 F1=HT(J)*.8499999+NS*(UK*TE+3.7*TA(J))
940 TW=(F1/((UK+3.7)*NS))
950 QIS=UK*AW*(TW-TE)*NS*N1(J)
960 QID=HT(J)*.8499999*AG*N1(J)
```

```
970 IF LA<=0 THEN 975
971 QXSI=LA-QIS
975 IF LA1<=0 THEN 1000
990 QXDI=LA1-QID
1000 ICD=(UA1/(.8499999*AG))*(TE-TA(J))
1010 F2=(UA*((3.7/UK)+1)+3.7*AW)*(TE-TA(J))
1020 ICS=F2/(.8499999*AW)
1030 IF ICD<0 THEN XCD=0:GOTO 1050
1040 XCD=(.0036*ICD)/(RTN(J)*RN(J)*HT(J))
1050 IF ICS<0 THEN XCS=0:GOTO 1070
1060 XCS=(.0036*ICS)/(RTN(J)*RN(J)*HT(J))
1070 F3=(A(J)+B(J)/R1(J))*XCD*(1+C(J)*XCD)
1080 F4=(A(J)+B(J)/R1(J))*XCS*(1+C(J)*XCS)
1090 PD=EXP(F3)
1100 PS=EXP(F4)
1110 QDD=PD*QID
1120 QDS=((UK*.8499999*AW)/(3.7+UK))*HT(J)*PS*N1(J)
1130 IF LA<=0 THEN 1145
1140 QXSZ=LA-QIS+QDS
1145 IF LA1<=0 THEN 1160
1150 QXDZ=LA1-QID+QDD
1160 IF LA1<=0 THEN FID=1:GOTO 1180
1170 FID=(1-QXDI/LA)
1180 IF (LA+LW)<=0 THEN FIS=1:GOTO 1200
1190 FIS=(1-QXSI/(LA+LW))
1200 IF LA1<=0 THEN XD=0:GOTO 1220
1210 XD=QID/LA1
1215 IF XD>4 THEN XD=4
1220 IF (LA+LW)<=0 THEN XS=0:GOTO 1240
1230 XS=(HT(J)*.8499999*AW*N1(J))/(LA+LW)
1235 IF XS>4 THEN XS=4
1240 FZD=(1-PD)*FID
1250 FZS=FIS-(UK/(3.7+UK))*PS*XS
1260 YD=(.123*AF*(TE-18.3)*N1(J))/QDD
1270 SB=(.12*AF*(TE-18.3)*N1(J))
1280 SW=((R0*CP*D1*D1)/(2*K1*86400!))*QIS
1290 YS=(SB+SW*.047)/QDS
1300 P1=(1-EXP(-.294*YD))^(.652)
1310 P2=(1-EXP(-.144*YS))^(.53)
1320 FD=P1*XD+(1-P1)*(3.082-3.142*PD)*(1-EXP(-.329*XD))
1330 FS=P2*FIS+.88*(1-P2)*(1-EXP(-1.26*FIS))
1340 IF FD>1 THEN FD=1
1350 IF FS>1 THEN FS=1
1360 QXD=(1-FD)*LA1
1370 QXS=(1-FS)*(LA+LW)
1390 ETAD=(LA1/QID)*FD
1400 L11=LA+LW
1410 IF L11<=0 THEN L11=0
1420 ETAS=(L11/QIS)*FS
1430 IF ETAD<0 THEN ETAD=0
1440 IF ETAS<0 THEN ETAS=0
1445 IF ETAD>1 THEN ETAD=1
1446 IF ETAS>1 THEN ETAS=1
1450 TNHD=TA(J)+(QID/(N1(J)*UA1*.024*3.6))
1460 TNHS=TA(J)+(QIS/(N1(J)*(UA+UW*AW)*NS))
1470 DELT1=TE-TNHD:DELT2=TE-TNHS
1480 PRINT J;TAB(5);INT(DELT1);TAB(15);INT(100*ETAD);TAB(25);INT(DELT2)
1490 PRINT INT(100*ETAS);TAB(45);INT(TNHD);TAB(55);INT(TNHS)
1500 LA1(J)=LA1:LA(J)=LA:LW(J)=LW:TW(J)=TW
1510 QIS(J)=QIS:QID(J)=QID:QXSI(J)=QXS$:QXDI(J)=QXDI:ICD(J)=ICD
1520 XCD(J)=XCD:XCS(J)=XCS:PD(J)=PD:PS(J)=PS:QDD(J)=QDD:QDS(J)=QDS
```

```
1530 QXDZ(J)=QXDZ:FID(J)=FID:FIS(J)=FIS:XD(J)=XD:XS(J)=XS:FZD(J)=FZD
1540 YD(J)=YD:YS(J)=YS:FD(J)=FD:FS(J)=FS:QXD(J)=QXD:QXS(J)=QXS
1550 ETAS(J)=ETAS:TNHD(J)=TNHD:TNHS(J)=TNHS:DELT1(J)=DELT1
1555 DDR(J)=DDR
1560 NEXT J
1561 PRINT"ENTER PRINT INDEX(1 TO PRINTER,0 NO PRINT)":INPUT PI
1562 IF PI=1 THEN GOSUB 3000
1570 PRINT"WOULD YOU LIKE ANOTHER RUN(1=YES,0=NO)":INPUT RI
1580 IF RI=1 THEN 1590
1585 END
1590 FOR J=1 TO 12
1600 LA1(J)=0:LA(J)=0:LW(J)=0:TW(J)=0:QIS(J)=0:QID(J)=0
1610 QXSI(J)=0:QXDI(J)=0:ICD(J)=0:ICS(J)=0:XCD(J)=0:XCS(J)=0:PD(J)=0
1620 QDD(J)=0:QDS(J)=0:QXSZ(J)=0:QXDZ(J)=0:FID(J)=0:FIS(J)=0:XD(J)=0
1630 FZD(J)=0:FZS(J)=0:YD(J)=0:YS(J)=0:FD(J)=0:FS(J)=0:QXD(J)=0
1640 ETAD(J)=0:ETAS(J)=0:TNHD(J)=0:TNHS(J)=0:DELT1(J)=0:DELT2(J)=0
1645 DDR(J)=0
1650 NEXT J
1660 GOTO 755
3000 LPRINT"THERMAL PERFORMANCE OF DIRECT GAIN HOUSE"
3010 LPRINT"----------------------------------------------------------------
3020 LPRINT"GLAZED AREA FLOOR AREA  RATIO OF GLAZED/FLOOR         TE
3030 LPRINT AG;TAB(20);AF;TAB(35);AG/AF;TAB(55);TE
3040 LPRINT
3050 LPRINT"MONTH DEGREE-DAYS                   LOAD     INPUT       DUMP      AUX
3060 LPRINT"        AT TE                                              "
3070 LPRINT"         (C-DAYS)                   (GJ)     (GJ)        (GJ)      (GJ)
3080 LPRINT
3090 FOR J=1 TO 12
3100 LPRINT J;TAB(15);INT(DDR(J));TAB(25);LA1(J)/1000;
3110 LPRINT TAB(35);QID(J)/1000;TAB(45);QDD(J)/1000;TAB(55);QXD(J)/1000;
3120 LPRINT
3130 NEXT J
3140 LPRINT
3141 LPRINT:LPRINT:LPRINT:LPRINT
3145 LPRINT"MONTH     UA      IC          PHI              XC       F          SLR
3150 LPRINT"        (W/C) (W/SQ.M)
3160 LPRINT
3170 FOR J=1 TO 12
3180 IF ICD(J)<=0 THEN ICD(J)=0
3190 LPRINT J;TAB(5);UA1;TAB(15);ICD(J);TAB(25);PD(J);TAB(35);XCD(J);
3200 LPRINT FD(J);TAB(55);XD(J);TAB(65);TE-TA(J)
3210 LPRINT
3220 NEXT J
3230 LPRINT
3240 LPRINT"MONTH    TEMPERATURE                            EFF        TEMPERATURE
3250 LPRINT"          TA   TE  TI                                          TE-TI
3260 LPRINT"              (C)                               (%)             (C)
3265 LPRINT
3270 FOR J=1 TO 12
3280 LPRINT J;TAB(5);TA(J);TAB(12);TE;TAB(16);TNHD(J);TAB(35);ETAD(J)
3285 LPRINT DELT1(J);
3300 LPRINT
3310 NEXT J
3320 LPRINT:LPRINT:LPRINT:LPRINT:LPRINT
3330 LPRINT"PERFORMANCE OF THE STORAGE-WALL SYSTEM"
3340 LPRINT
3350 LPRINT"COLLECTOR    FLOOR     AREA RATIO(AC/AF)    THERMAL PROPERTIES
3360 LPRINT"  AREA       AREA                                 STORAGE WALL
3365 LPRINT"                                             U    STORAGE     K
3366 LPRINT"                                                  CAPACITY
```

```
3367 LPRINT"  (SQ.M)     (SQ.M.)                         (W/SQ.MC) (MJ/CM)
"
3368 LPRINT
3370 LPRINT AW;TAB(10);AF;TAB(15);AW/AF;TAB(35);UW;TAB(45);(RO*CF)
3375 LPRINT TAB(55);K1;TAB(65);D1
3380 LPRINT:LPRINT:LPRINT
3390 LPRINT"MONTH DEGREE    LOAD                                   INPUT
"
3400 LPRINT"       DAYS
"
3401 LPRINT"        AT TE    LA          LW
3402 LPRINT"     (C-DAYS)   (GJ)        (GJ)                        (GJ)
)"
3430 LPRINT
3440 FOR J=1 TO 12
3450 LPRINT J;TAB(5);DDR(J);TAB(15);LA(J)/1000;TAB(25);LW(J)/1000
3460 LPRINT QIS(J)/1000;TAB(55);QDS(J)/1000;TAB(65);QXS(J)/1000;
3470 LPRINT
3480 NEXT J
3490 LPRINT:LPRINT:LPRINT:LPRINT
3500 LPRINT"MONTH        UA        IC        PHI           XC     F        SLR
3510 LPRINT"            (W/C)   (W/SQ.M)
"
3520 LPRINT
3530 FOR J=1 TO 12
3540 IF ICS(J)<=0 THEN ICS(J)=0
3550 LPRINT J;TAB(5);UA;TAB(15);ICS(J);TAB(25);PS(J);TAB(35);XCS(J)
3560 LPRINT FS(J);TAB(55);XS(J);TAB(65);TE-TA(J)
3570 LPRINT
3580 NEXT J
3590 LPRINT:LPRINT:LPRINT:LPRINT
3600 LPRINT"              TEMPERATURE                              EFF
3610 LPRINT"     TA             TW    TE          TI           (%)        TE-TI
3620 LPRINT"              (C)                                              (C)
3630 LPRINT
3640 FOR J=1 TO 12
3650 LPRINT J;TAB(5);TA(J);TAB(15);TW(J);TAB(25);TE;TAB(35);TNHS(J);
3660 LPRINT ETAS(J);TAB(65);DELT2(J);
3670 LPRINT
3680 NEXT J
3690 RETURN
```

```
10 DIM N1(12),TA(12),DD(12),N(12),H(12),H0(12),KT(12),DEC(12),W(12),DL(12)
20 DIM RB(12),UW(8),UR(9),RDH(12),R(12),RBN(12),RDN(12),RTN(12),RDHN(12)
30 DIM R1(12),HT(12),A(12),B(12),C(12)
35 DIM DELT(12),AG(9),UAH(12,9),IC(12,9),XC(12,9),PHI(12,9),QI(12),L(12)
36 DIM QAZ(12),FI(12),FZ(12),Y1(12),XI(12),F(12),QA(12),QD(12)
37 DIM TNH(12),ETA(12),TI(12),DIF(12)
40 PRINT"ENTER THERMOSTAT SET TEMP.":INPUT TE
50 FOR J=1 TO 12
60 READ N1(J),TA(J)
70 DATA 31,15.9,28,18.2,31,18.2,30,20.3,31,22,30,22.8,31,23.2,31,22.5
75 DATA 30,19.8,31,17.8,30,16.1,31,14.3
76 DD(J)=N1(J)*(TE-TA(J))
80 NEXT J
100 FOR J=1 TO 12
110 READ N(J),H(J),H0(J)
120 DATA 21,18.7,28.93,49,20.9,32.31,80,22.7,35.43,110,24.1,37.67,141,24.8
130 DATA 171,24.8,38.1,202,24.8,37.98,233,24.8,37.69,264,23.8,36.14,295,21
140 DATA 325,19.8,29.67,355,18.4,27.93
150 NEXT J
151 FOR H=1 TO 8
152 READ UW(H)
153 DATA 1.47,1.29,3.36,0.72,5.34,2.89,2.93,5.19
154 NEXT H
155 FOR M=1 TO 9
156 READ UR(M)
157 DATA 2.26,2.1,1.83,2.11,2.72,10.32,7.72,2.86,2.3
158 NEXT M
160 L=(3.142/180)*15:COSL=COS(L):SINL=SIN(L):TANL=TAN(L)
170 FOR J=1 TO 12
180 KT(J)=H(J)/H0(J)
190 DEC=(23.45)*SIN((3.142/180)*(360/365)*(N(J)+284)):DEC(J)=DEC
200 DEC1=(3.142/180)*DEC:COSD=COS(DEC1):SIND=SIN(DEC1):TAND=TAN(DEC1)
210 X1=-TAND*TANL:X2=-ATN(X1/SQR(1-X1*X1))+1.5708:W(J)=(180/3.142)*X2
220 DL(J)=(180/3.142)*(2/15)*X2
230 FOR Y=1 TO 13
240 HA=(3.142/180)*15*((5+Y)-12):COSH=COS(HA):SINH=SIN(HA)
250 X3=COSD*COSL*COSH+SINH*SIND
260 SAL=ATN(X3/SQR(1-X3*X3))
270 X4=-COSD*(SINH/COS(SAL))
275 IF X4*X4>1 THEN 290
280 SAZ=ATN(X4/SQR(1-X4*X4))
290 IF SIN(SAL)=0 THEN 310
300 R=COS(SAL)*(COS(SAZ)/SIN(SAL))
310 IF R<0 THEN R=0
320 IF R>3 THEN R=3
325 PRINT Y+5,SAL*(180/3.142),SAZ*(180/3.142),DEC(J),R
330 RT=RT+R
340 NEXT Y
350 RB(J)=RT/DL(J):PRINT"RB";RB(J)
360 RDH(J)=1.39-4.03*KT(J)+5.53*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)
370 R(J)=(1-RDH(J))*RB(J)+RDH(J)
375 PRINT"RT=";R(J)
380 RDHN(J)=1.0045+.04349*KT(J)-3.5227*KT(J)*KT(J)+2.63*KT(J)*KT(J)*KT(J)
390 RDN(J)=(3.142/24)*((1-COS(X2))/(SIN(X2)-(3.142/180)*W(J)*COS(X2)))
400 RTN(J)=RDN(J)*(1.07+.025*SIN(X2-3.142/3))
410 X5=COSD*COSL+SIND*SINL
420 SALN=ATN(X5/SQR(1-X5*X5))
430 RBN(J)=COS(SALN)/SIN(SALN)
440 RN(J)=(1-(RDN(J)/RTN(J))*RDHN(J))*RBN(J)+(RDN(J)/RTN(J))*RDHN(J)
```

```
450 R1(J)=R(J)/RN(J)
460 HT(J)=R(J)*H(J)
480 RT=0
490 NEXT J
495 PRINT"ENTER PRINTING INDEX,1 TO PRINTER 0 TO SCREEN":INPUT PI
496 IF PI=0 THEN 760
500 LPRINT"TABLE1:SOLAR RADIATION FALLING ON THE TILTED AND HORIZONTAL"
510 LPRINT"        SURFACES OF A HOUSE IN THE YEMEN EVALUATED ON 21ST.DAY"
520 LPRINT"MONTH  SOLAR RADIATION IN(MJ/M-DAY) CLEARNESS FACTOR          "
530 LPRINT"        EXT.  HORIZONTAL  VERTICAL                             "
540 LPRINT"-----------------------------------------------------------------"
550 LPRINT
560 FOR J=1 TO 12
570 LPRINT J;TAB(10);H0(J);TAB(20);H(J);TAB(25);HT(J);TAB(45);KT(J);
580 LPRINT
590 NEXT J
600 LPRINT:LPRINT:LPRINT:LPRINT
610 LPRINT"TABLE2:COMPONENT OF SOLAR RADIATION AS EVALUATED ON THE 21ST
620 LPRINT"MONTH    DIFFUSE       DIRECT       GLOBAL
630 LPRINT"-------------------------------------------------------------------
640 LPRINT
650 FOR J=1 TO 12
660 LPRINT J;TAB(10);RDH(J);TAB(30);RB(J);TAB(55);R(J)
670 NEXT J
680 LPRINT:LPRINT:LPRINT
690 LPRINT"TABLE3:COMPONENT OF SOLAR RADIATION AS EVALUATED AT THE SOLAR
700 LPRINT"                    OF THE 21ST DAY OF THE MONTH
710 LPRINT
720 FOR J=1 TO 12
730 LPRINT J;TAB(10);RBN(J);TAB(20);RN(J);TAB(30);RDN(J);TAB(40);RTN(J)
740 LPRINT RDHN(J);TAB(60);R1(J)
750 NEXT J
760 PRINT"SPECIFY THE TYPE OF WALL(INT.FROM 1 TO 8)":INPUT H
765 PRINT"ENTER FLOOR AREA(MULTIPLE OF 44 SQ.METER)":INPUT AF
770 FOR J=1 TO 12
780 A(J)=2.943-9.271*KT(J)+4.031*KT(J)*KT(J)
790 B(J)=-4.345+8.853001*KT(J)-3.602*KT(J)*KT(J)
800 C(J)=-.17-.306*KT(J)+2.936*KT(J)*KT(J)
805 DELT(J)=TE-(5.42/UW(H))-TA(J)
810 IF DELT(J)<0 THEN DELT(J)=0
820 FOR K=1 TO 8
825 AG(K)=5*K
830 UAH(J,K)=UW(H)*AF+4.3*AG(K)
840 IC(J,K)=(UAH(J,K)*DELT(J))/(.8499999*AG(K))
845 XC(J,K)=(IC(J,K)*(3.6/1000))/(RTN(J)*RN(J)*H(J))
850 F12=(A(J)+(B(J)/R1(J)))*XC(J,K)*(1+C(J)*XC(J,K))
860 PHI(J,K)=EXP(F12)
870 NEXT K
880 NEXT J
890 K=1
900 FOR J=1 TO 12
910 C1=.123*AF*(TE-18.3)*N1(J)
915 C2=(.13*AF*3.6)*N1(J)
920 QI(J)=AG(K)*.8499999*HT(J)*N1(J)
925 TNH(J)=TA(J)+(C2+QI(J))/(UAH(J,K)*N1(J)*.024*3.6)
926 DIF=TE-TNH(J)
930 L(J)=UAH(J,K)*DD(J)*.024*3.6
940 QAI(J)=L(J)-QI(J)
950 QAZ(J)=L(J)-(1-PHI(J,K))*QI(J)
960 IF QAI(J)<0 THEN QAI(J)=0
970 IF QAZ(J)<0 THEN QAZ(J)=0
975 IF L(J)=0 THEN FI(J)=1:GOTO 990
```

```
980 FI(J)=(1-QAI(J)/L(J))
990 FZ(J)=(1-PHI(J,K))*FI(J)
1000 Y1(J)=C1/(PHI(J,K)*QI(J))
1010 P=(1-EXP(-.294*Y1(J)))^(.652)
1011 IF L(J)=0 THEN XI(J)=1:GOTO 1020
1015 XI(J)=QI(J)/L(J)
1016 IF XI(J)<0 THEN XI(J)=0
1017 IF XI(J)>4 THEN XI(J)=4
1020 Q1=3.082-3.142*PHI(J,K)
1030 Q2=1-EXP(-.329*XI(J))
1040 F(J)=P*XI(J)+(1-P)*Q1*Q2
1060 QA(J)=(1-F(J))*L(J)
1070 QD(J)=PHI(J,K)*QI(J)
1075 ETA(J)=(L(J)*F(J))/QI(J)
1076 IF L(J)=0 THEN TI(J)=TNH(J):GOTO 1078
1077 TI(J)=TNH(J)+(QA(J)/L(J))*(TE-TA(J))
1078 DIF(J)=DIF
1079 PRINT J,TNH(J),TI(J),DIF(J),ETA(J)
1080 NEXT J
1085 PRINT "ENTER PRINT INDEX(1 HARD COPY,0 ANOTHER RUN)"
1086 INPUT PII
1087 IF PII=0 THEN 1406
1090 LPRINT"TE      GLAZED AREA      FLOOR AREA  RATIO OF GLAZED-TO-FLOOR
1100 LPRINT"(C)        (SQ.M)           ( SQ.M. )
1110 LPRINT"--------------------------------------------------------------
1120 LPRINT
1125 LPRINT TE,AG(K),AF,AG(K)/AF
1126 LPRINT:LPRINT:LPRINT
1130 LPRINT"MONTH       UA            IC            XC            PHI
1140 LPRINT"           (W/C)        (W/SQ.M)
1150 LPRINT
1160 FOR J=1 TO 12
1170 LPRINT J;TAB(10);UAH(J,K);TAB(20);IC(J,K);TAB(30);XC(J,K);TAB(40);PHI
1180 LPRINT TAB(50);DELT(J);
1190 LPRINT
1200 NEXT J
1210 LPRINT:LPRINT:LPRINT
1220 LPRINT"MONTH     DD             Y            SLR            SOLAR FRACTION
1230 LPRINT"        (C-DAY )                              ITC       FTC        ZTC
1240 LPRINT
1250 FOR J=1 TO 12
1260 IF DD(J)<0 THEN DD(J)=0
1270 LPRINT J;TAB(10);DD(J);TAB(20);Y1(J);TAB(35);XI(J);TAB(45);FI(J)
1280 LPRINT F(J);TAB(65);FZ(J)
1290 LPRINT
1300 NEXT J
1310 LPRINT:LPRINT:LPRINT
1320 LPRINT"MONTH       SOLAR      LOAD       DUMPED              AUX. ENERGY
1330 LPRINT"            INPUT                 ENERGY        ITC     FTC     ZTC
1340 LPRINT"            (GJ)       (GJ)       (GJ)                  (GJ)
1345 LPRINT
1350 FOR J=1 TO 12
1360 LPRINT J;TAB(10);QI(J)/1000;TAB(20);L(J)/1000;TAB(30);QD(J)/1000;
1370 LPRINT QAI(J)/1000;TAB(50);QA(J)/1000;TAB(60);QAZ(J)/1000;
1380 LPRINT
1390 NEXT J
1395 LPRINT:LPRINT:LPRINT
1396 LPRINT"WALL U-VALUE=";UW(H);"W/SQ.M C"
1397 LPRINT"MONTH";TAB(10);"TE";TAB(30);"TNH";TAB(40);"TE-TNH";TAB(50);
```

```
1398 FOR J=1 TO 12
1399 LPRINT J;TAB(10);TE;TAB(30);TNH(J);TAB(40);TI(J);TAB(50);ETA(J)*100;
1400 LPRINT TAB(60);DIF(J)
1405 NEXT J
1406 FOR J=1 TO 12
1410 QI(J)=0:L(J)=0:QD(J)=0:QAI(J)=0:QA(J)=0:QAZ(J)=0:Y1(J)=0:FI(J)=0:F(J)
1420 FZ(J)=0:ETA(J)=0:TNH(J)=0:DIF=0
1430 NEXT J
1440 PRINT"WOULD YOU LIKE ANOTHER RUN FOR DIFFERENT GLAZING AND SAME MATE"
1450 PRINT"ENTER 1 FOR YES 0 FOR NO":INPUT RI
1455 IF RI=0 THEN 1480
1460 IF RI=1 THEN K=K+1
1465 PRINT"K=";K
1470 IF K<8 THEN 900
1480 FOR K=1 TO 8
1490 FOR J=1 TO 12
1500 UAH(J,K)=0:AG(K)=0:IC(J,K)=0:XC(J,K)=0:PHI(J,K)=0
1510 NEXT J
1520 NEXT K
1530 PRINT"WOULD YOU LIKE TO RUN THE PROG.FOR ANOTHER MATERIAL"
1540 PRINT"ENTER 1 FOR YES 0 FOR NO":INPUT RII
1550 IF RII=1 THEN 760
1560 END
```

```
10 DIM HO(12),H(12),HTS(12),HTN(12),HTE(12),TA(12),ND(12),N1(12),NN(12)
20 DIM QI(12),TRS(12),TRC(12),QLS(12),QLC(12),G(12),QT(12),FS(12),FC(12)
30 DIM ETAS(12),EFFS(12),EFFC(12),TNHS(12),TNHC(12),QAUXS(12),QAUXC(12)
40 DIM TIS(12),TIC(12),HT(12),XX(12),QEXS(12),QEXC(12),QDS(12),QDC(12)
50 DIM DCS(12),DCC(12)
200 FOR J=1 TO 12
210 READ HO(J),H(J),HTS(J),HTN(J),HTE(J),TA(J),ND(J),N1(J)
220 DATA 28.93,18.7,15.34,0.65,7.56,15.4,9.1,31
230 DATA 32.31,20.9,12.09,0.86,8.64,17.5,9.9,28
240 DATA 35.43,22.7, 6.91,0.86,9.50,18.6,9.0,31
250 DATA 37.67,24.1, 1.29,2.16,9.94,19.6,9.1,30
260 DATA 38.21,24.8, 0.86,6.48,10.4,21.6,8.9,31
270 DATA 38.10,24.8, 0.86,8.64,9.94,22.7,8.8,30
280 DATA 37.93,24.8, 0.86,6.48,10.4,22.2,7.1,31
290 DATA 37.69,24.8, 1.29,2.16,9.94,21.8,7.4,31
300 DATA 36.14,23.8, 6.91,0.86,9.50,18.9,8.7,30
310 DATA 33.00,21.9,12.09,0.86,8.64,16.5,10.,31
320 DATA 29.67,19.8,15.34,0.65,7.56,15.1,9.7,30
330 DATA 27.93,18.4,16.20,0.65,7.13,13.9,9.0,31
340 NN(J)=24-ND(J)
350 NEXT J
500 PRINT"ENTER THE STORAGE FLOOR AREA IN(SQ.M.)":INPUT AF
515 PRINT"ENTER AC":INPUT AC
530 PRINT"ENTER TC":INPUT TC
540 PRINT"ENTER TTC":INPUT TTC
550 GS=1.47*AC*2.64
560 GC=3.36*AC*2.64
570 GW=4.3*AC*1.36
580 GR=3.88*AF
590 UAS=GS+GW+GR
600 UAC=GC+GW+GR
610 NS=.024*3.6
620 BS=UAS/AC
630 BC=UAC/AC
820 FOR J=1 TO 12
830 QI(J)=.13*3.6*N1(J)*AF
840 TRS(J)=TC-(QI(J)/(UAS*N1(J)*NS))
850 TRC(J)=TC-(QI(J)/(UAC*N1(J)*NS))
860 QLS(J)=UAS*NS*N1(J)*(TRS(J)-TA(J))
870 QLC(J)=UAC*NS*N1(J)*(TRC(J)-TA(J))
880 G=.12*HTN(J)+.24*HTE(J)
890 G(J)=(1+G/HTS(J))
900 QT(J)=AC*(.8*.8499999)*HTS(J)*G(J)*N1(J)
910 FS(J)=(1-.75*(QLS(J)/QT(J)))
920 FC(J)=(1-.75*(QLC(J)/QT(J)))
930 IF FS(J)<0 THEN FS(J)=0
940 IF FC(J)<0 THEN FC(J)=0
950 IF FS(J)>4 THEN FS(J)=4
960 IF FC(J)>4 THEN FC(J)=4
970 ETAS=(1-EXP(-ND(J)/TTC))*(1-EXP(-NN(J)/TTC))
980 ETAS(J)=(TTC/ND(J))*(ETAS/(1-EXP(-24/TTC)))
990 EFFS(J)=(1-FS(J)*ETAS(J))
1000 EFFC(J)=(1-FC(J)*ETAS(J))
1010 IF EFFS(J)>1 THEN EFFS(J)=1
1020 IF EFFS(J)<-1 THEN EFFS(J)=-1
1030 IF EFFC(J)>1 THEN EFFC(J)=1
1040 IF EFFC(J)<-1 THEN EFFC(J)=-1
1050 TNHS(J)=TA(J)+((QI(J)+QT(J))/(UAS*NS*N1(J)))
1060 TNHC(J)=TA(J)+((QI(J)+QT(J))/(UAC*NS*N1(J)))
```

```
1070 QAUXS(J)=QLS(J)-EFFS(J)*QT(J)
1080 QAUXC(J)=QLC(J)-EFFC(J)*QT(J)
1090 TIS(J)=TNHS(J)+(QAUXS(J)/QLS(J))*(TC-TA(J))
1100 TIC(J)=TNHC(J)+(QAUXC(J)/QLC(J))*(TC-TA(J))
1110 HT(J)=(11.6)*G(J)*(.8*.8499999)*HTS(J)
1120 XX(J)=(TC-TA(J))/HT(J)
1130 IF QAUXS(J)<0 THEN QCS=QCS+QAUXS(J)
1140 IF QAUXS(J)>0 THEN QHS=QHS+QAUXS(J)
1150 IF QAUXC(J)<0 THEN QCC=QCC+QAUXC(J)
1160 IF QAUXC(J)>0 THEN QHC=QHC+QAUXC(J)
1170 IF (TIS(J)-TC)<=0 THEN QEXS(J)=0:GOTO 2000
1180 QEXS(J)=(UAS)*NS*N1(J)*(TIS(J)-TC)
2000 IF (TIC(J)-TC)<=0 THEN QEXC(J)=0:GOTO 2030
2010 QEXC(J)=(UAC)*NS*N1(J)*(TIC(J)-TC)
2030 IF QEXS(J)>QT(J) THEN QDS(J)=QT(J):GOTO 2060
2040 IF QEXS(J)=0 THEN QDS(J)=0:GOTO 2060
2050 QDS(J)=QT(J)-QEXS(J)
2060 IF QEXC(J)>QT(J) THEN QDC(J)=QT(J):GOTO 2090
2070 IF QEXC(J)=0 THEN QDC(J)=0:GOTO 2090
2080 QDC(J)=QT(J)-QEXC(J)
2090 DCS(J)=QDS(J)/QT(J)
2100 DCC(J)=QDC(J)/QT(J)
2280 PRINT J;TAB(5);QLS(J);TAB(15);QT(J);TAB(25);QAUXS(J);TAB(35);XX(J);
2290 PRINT TAB(45);FS(J);TAB(55);EFFS(J);TAB(65);TC-TA(J)
2325 PRINT
2330 PRINT
2340 PRINT
2345 PRINT
2365 PRINT TAB(5);TIS(J);TAB(15);TIS(J)-TC;TAB(25);DCS(J);TAB(35);QEXS(J);
2366 PRINT TAB(45);QDS(J)
2369 PRINT"------------------------------------------------------------
2370 ETAST=ETAST+ETAS(J)
2371 NEXT J
2374 GOTO 4040
2380 LPRINT"TC       ETAS          UA             TTC       AC      AF       "
2390 LPRINT TC;TAB(5);ETAST/12;TAB(15);UAS;UAC;TAB(35);TTC;TAB(45);AC;
2450 LPRINT
2455 QHS=QHS/1000:QCS=QCS/1000:QHC=QHC/1000:QCC=QCC/1000
2460 LPRINT"MONTH TI        TI-TC    TC-TA     DELT/HT           F          EFF
2470 LPRINT"        (C)        (C)        (C)      (C SQ.M/W)
2480 LPRINT
2490 FOR J=1 TO 12
2500 LPRINT J;TAB(5);TIS(J);TAB(15);TIS(J)-TC;TAB(25);TC-TA(J);TAB(35)
2510 LPRINT TAB(50);FS(J);TAB(60);EFFS(J);TAB(70);DCS(J)
2520 LPRINT
2530 LPRINT TAB(5);TIC(J);TAB(15);TIC(J)-TC;TAB(50);FC(J);TAB(60);EFFC(J);
2540 LPRINT TAB(70);DCC(J)
2550 LPRINT"------------------------------------------------------------
2560 NEXT J
2570 LPRINT"MONTH     LOAD          SOLAR           AUX              DUMP.ENE
2580 LPRINT"        ST         CON             ST          CON       ST
2590 LPRINT"            (GJ/MONTH)   (GJ/MONTH)     (GJ/MONTH)           (GJ/MON
2600 LPRINT
2610 FOR J=1 TO 12
2620 LPRINT J;TAB(5);QLS(J);QLC(J);TAB(35);QT(J);TAB(45);QAUXS(J);QAUXC(J)
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```
2630 LPRINT TAB(55);QDS(J);QDC(J)
2640 LPRINT"-------------------------------------------------------------------
2650 NEXT J
2660 LPRINT"ANNUAL               HEATING            COLLING          TOTAL
2670 LPRINT TAB(25);QHS;TAB(35);QCS;TAB(45);QHS-QCS
2680 LPRINT
2690 LPRINT TAB(25);QHC;TAB(35);QCC;TAB(45);QHC-QCC
2700 LPRINT"-------------------------------------------------------------------
4040 QCS=0:QCS1=0:QHS=0:QHS1=0
4050 QCC=0:QCC1=0:QHC=0:QHC1=0
4060 ETAST=0
5010 PRINT"ANOTHER RUN(RI=1),STOP(RI=0)":INPUT RI
5020 IF RI=1 THEN 515
5030 END
```

```
10 DIM N1(12),TA(12),ND(12),NN(12),DD(12),N(12),H(12),H0(12)
11 DIM UW(8),RO(9),CP(9),U(9),K(9),D(9)
15 DIM KT(12),DEC(12),W(12),DL(12),RBS(12),RBN(12),RBE(12),RBW(12)
20 DIM RDH(12),RS(12),RN(12),RE(12),RW(12),RBN1(12),RDN(12),RTN(12)
30 DIM RDHN(12),RN1(12),R1(12),HTS(12),HTN(12),HTE(12),HTW(12),A(12),B(12)
35 DIM QI(12),TR(12),G(12),QT(12),QL(12),F(12),ETAS(12),EFF(12),QAUX(12)
36 DIM TNH(12),TI(12),NH(12),ABCS(12),DELT1(12),DELT2(12),DELT3(12)
37 DIM XF(12),XE(12),XA(12),XH(12)
40 LPRINT"MONTH   TA          ND      SOLAR ENERGY FALLING ON HOUSE WALLS"
41 LPRINT"        (C)         (HR)          (MJ/SQ.M DAY )                 "
42 LPRINT"                            HORZ     SOUTH   NORTH   EAST   WEST "
50 FOR J=1 TO 12
60 READ N1(J),TA(J)
70 DATA 31,15.4,28,17.5,31,18.6,30,19.6,31,21.6,30,22.7,31,22.2,31,21.8
75 DATA 30,18.9,31,16.5,30,15.1,31,13.9
80 NEXT J
90 FOR J=1 TO 12
95 READ ND(J)
100 DATA 9.1,9.9,9,9.1,8.9,8.8,7.1,7.4,8.7,10.1,9.7,9
105 NN(J)=24-ND(J)
106 NEXT J
107 FOR J=1 TO 12
110 READ N(J),H(J),H0(J)
120 DATA 15,18.7,28.93,47,20.9,32.31,74,22.7,35.43,105,24.1,37.67,135,24.8
130 DATA 166,24.8,38.1,196,24.8,37.98,227,24.8,37.69,258,23.8,36.14,288,21
140 DATA 319,19.8,29.67,349,18.4,27.93
150 NEXT J
151 FOR H=1 TO 8
152 READ UW(H)
153 DATA 1.47,1.29,3.36,0.72,5.34,2.89,2.93,5.19
154 NEXT H
155 FOR M=1 TO 9
156 READ RO(M),CP(M),U(M),K(M),D(M)
157 DATA 1520,837,2.26,0.465,0.140
158 DATA 1520,837,2.10,0.465,0.135
159 DATA 1520,837,1.83,0.465,0.111
160 DATA 2110,897,2.11,1.745,0.199
161 DATA 2110,897,2.72,1.745,0.126
162 DATA 2110,897,10.3,1.919,0.155
163 DATA 2110,897,7.72,1.745,0.215
164 DATA 2110,897,2.86,1.745,0.215
165 DATA 1700,897,2.30,2.271,0.350
166 UK(M)=(8.3*K(M))/(K(M)+D(M)*8.3)
167 TTC(M)=(RO(M)*D(M)*CP(M)*.001)/(3.6*UK(M))
168 NEXT M
169 L=(3.142/180)*15:COSL=COS(L):SINL=SIN(L):TANL=TAN(L)
170 FOR J=1 TO 12
180 KT(J)=H(J)/H0(J)
190 DEC=(23.45)*SIN((3.142/180)*(360/365)*(N(J)+284)):DEC(J)=DEC
200 DEC1=(3.142/180)*DEC:COSD=COS(DEC1):SIND=SIN(DEC1):TAND=TAN(DEC1)
210 X1=-TAND*TANL:X2=-ATN(X1/SQR(1-X1*X1))+1.5708:W(J)=(180/3.142)*X2
220 DL(J)=(180/3.142)*(2/15)*X2
230 FOR Y=1 TO 13
240 HA=(3.142/180)*15*((5+Y)-12.5):COSH=COS(HA):SINH=SIN(HA)
250 X3=COSD*COSL*COSH+SINH*SIND
260 SAL=ATN(X3/SQR(1-X3*X3))
270 X4=-COSD*(SINH/COS(SAL))
275 IF X4*X4>1 THEN 290
280 SAZ=ATN(X4/SQR(1-X4*X4))
```

```
290 IF SIN(SAL)=0 THEN 310
300 RS=COS(SAL)*(COS(SAZ)/SIN(SAL))
301 RN=-RS
302 RE=-COS(SAL)*(SIN(SAZ)/SIN(SAL))
303 RW=-RE
304 IF RS<0 THEN RS=0
305 IF RS>3 THEN RS=3
306 IF RN>3 THEN RN=3
307 IF RN<0 THEN RN=0
308 IF RE>3 THEN RE=3
309 IF RE<0 THEN RE=0
310 IF RW>3 THEN RW=3
311 IF RW<0 THEN RW=0
320 RTS=RTS+RS
321 RTN=RTN+RN
322 RTE=RTE+RE
323 RTW=RTW+RW
330 RE=0:RW=0:RS=0:RN=0
340 NEXT Y
350 RBS(J)=RTS/DL(J)
351 RBN(J)=RTN/DL(J)
352 RBE(J)=RTE/DL(J)
353 RBW(J)=RTW/DL(J)
360 RDH(J)=1.39-4.03*KT(J)+5.53*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)
370 RS(J)=(1-RDH(J))*RBS(J)+RDH(J)
371 RN(J)=(1-RDH(J))*RBN(J)+RDH(J)
372 RE(J)=(1-RDH(J))*RBE(J)+RDH(J)
373 RW(J)=(1-RDH(J))*RBW(J)+RDH(J)
380 RDHN(J)=1.0045+.04349*KT(J)-3.5227*KT(J)*KT(J)+2.63*KT(J)*KT(J)*KT(J
390 RDN(J)=(3.142/24)*((1-COS(X2))/(SIN(X2)-(3.142/180)*H(J)*COS(X2)))
400 RTN(J)=RDN(J)*(1.07+.025*SIN(X2-3.142/3))
410 X5=COSD*COSL+SIND*SINL
420 SALN=ATN(X5/SQR(1-X5*X5))
430 RBN1(J)=COS(SALN)/SIN(SALN)
440 RN1(J)=(1-(RDN(J)/RTN(J))*RDHN(J))*RBN1(J)+(RDN(J)/RTN(J))*RDHN(J)
450 R1(J)=RS(J)/RN1(J)
451 HTS(J)=RS(J)*H(J)
452 HTN(J)=RN(J)*H(J)
453 HTE(J)=RE(J)*H(J)
454 HTW(J)=RW(J)*H(J)
460 LPRINT J;TAB(10);TA(J);TAB(20);ND(J);TAB(25);H(J);TAB(30);HTS(J);
461 A(J)=2.943-9.271*KT(J)+4.031*KT(J)*KT(J)
462 B(J)=-4.345+8.853001*KT(J)-3.602*KT(J)*KT(J)
463 C(J)=-.17-.306*KT(J)+2.936*KT(J)*KT(J)
465 LPRINT TAB(40);HTN(J);TAB(50);HTW(J);TAB(60);HTE(J)
466 LPRINT"-----------------------------------------------------------------"
480 RTS=0:RTN=0:RTE=0:RTW=0
490 NEXT J
495 LPRINT"MONTH  TI    TI-TC   NH    ABC        ENERGY(GJ)/MONTH
496 LPRINT"        (C)          (DAY)            SOL      LOAD      AUX
500 PRINT"ENTER RATIO OF EAST WALL LENGTH TO THAT OF SOUTH(1 TO 3)"
510 PRINT"ENTER WINDOW SIZING INDEX(MIN 1,MAX 4,AV 2.4)":INPUT WS
520 PRINT "ENTER TYPE OF EXT.WALL(1 STONE,3 CONCRETE)":INPUT H
530 PRINT"ENTER TYPE OF ROOF CONSTR.MATERIAL(1 TO 9)":INPUT M
540 PRINT"ENTER FLOOR AREA OF THE CONSIDERED HOUSE":INPUT AF
545 PRINT"ENTER COLLECTOR AREA":INPUT AC
550 PRINT"ENTER TC":INPUT TC
555 FOR Y=1 TO 5:TTC=5*Y
560 G1=UW(H)*AC*(1+2*RL1)*(1-.05*WS)
580 G2=4.3*AC*(1+.05*WS+.1*WS*RL1)
590 G3=(U(M)+.6+.34*3)*AF
```

```
610 UA=G1+G2+G3:PRINT"UA=";UA
620 NS=.024*3.6
630 B=UA/AC
640 FOR J=1 TO 12
650 QI(J)=.13*3.6*N1(J)*AF
660 DELT=(QI(J)/(N1(J)*NS*UA)):TR(J)=TC-DELT
670 G4=.05*WS*HTN(J)+.05*WS*RL1*(HTE(J)+HTW(J))
680 G(J)=(1+G4/HTS(J))
690 QT(J)=AC*(.8*.8499999)*HTS(J)*G(J)*N1(J)
700 QL(J)=UA*N1(J)*NS*(TR(J)-TA(J))
710 F(J)=(1-.75*(QL(J)/QT(J)))
720 ETAS=(1-EXP(-ND(J)/TTC))*(1-EXP(-NN(J)/TTC))
730 ETAS(J)=(TTC/ND(J))*(ETAS/(1-EXP(-24/TTC)))
740 IF F(J)<0 THEN F(J)=0
750 EFF(J)=1-F(J)*ETAS(J)
760 IF EFF(J)>1 THEN EFF(J)=1
770 IF EFF(J)<-1 THEN EFF(J)=-1
780 QAUX(J)=QL(J)-EFF(J)*QT(J)
790 IF QAUX(J)<0 THEN QAUXC=QAUXC+QAUX(J)
800 IF QAUX(J)>0 THEN QAUXH=QAUXH+QAUX(J)
810 ETAST=ETAST+ETAS(J)
820 DEL1=(QI(J)+QT(J))/(NS*UA*N1(J)):TNH(J)=TA(J)+DEL1
830 TI(J)=TNH(J)+(QAUX(J)/QL(J))*(TC-TA(J))
831 IF TI(J)<TR(J) THEN TI(J)=TR(J)
835 IF TI(J)>TC THEN GOSUB 5000
840 NH(J)=-(1-TI(J)/TC)*N1(J)*24
876 QEX=QEX/1000:QT(J)=QT(J)/1000:QAUX(J)=QAUX(J)/1000:QL(J)=QL(J)/1000
877 QS=QS/1000:QAUX1=QAUX1/1000
896 LPRINT J;TAB(5);TI(J);TAB(15);TI(J)-TC;TAB(25);NH(J)/24;TAB(35);ABCS;
897 LPRINT TAB(45);QT(J);TAB(55);QL(J);TAB(65);QAUX(J)
898 LPRINT TAB(5);TI1;TAB(45);QS;TAB(65);QAUX1
899 LPRINT"------------------------------------------------------------"
900 DELT1(J)=TC-TA(J)
910 DELT2(J)=TR(J)-TA(J)
920 DELT3(J)=TI(J)-TC
925 K1=((UA*NS)/(AC*.8*.8499999*G(J)))
930 XF(J)=K1*(DELT2(J)/HTS(J))
940 XE(J)=K1*ETAS(J)*(DELT2(J)/HTS(J))
950 XA(J)=((B*NS)/(.8*.8499999))*(DELT3(J)/HTS(J))
960 XH(J)=DELT3(J)
965 QS=0:TI1=0:EFF1=0:QAUX1=0:ABCS=0:F1=0:QEX=0:QAB=0:TNH1=0
970 NEXT J
980 LPRINT"              SYSTEM PARAMETERS                  "
981 LPRINT"AF      AC      B      UA      TTC      TC      ETAS    LR    WIND"
982 LPRINT AF;AC;B;UA;TTC;TC;ETAST/12;LR1;WS
1000 LPRINT"MONTH     TI        F-FACTOR       EFF       (TR-TA)/HTS        "
1015 LPRINT"                                              (SQ.M C/W )      "
1020 LPRINT
1030 FOR J=1 TO 12
1035 XX=(NS/(.8*.8499999))*(DELT2(J)/(G(J)*HTS(J)))
1040 LPRINT J;TAB(10);TI(J);TAB(20);F(J);TAB(30);EFF(J);TAB(50);XX
1060 LPRINT"------------------------------------------------------------"
1070 NEXT J
1080 PRINT"ANNUAL AUX                 HEATING       COOLING"
1090 PRINT"                                (GJ/MONTH)       "
1095 LPRINT"ANNUAL AUX NEEDS(GJ)     HEATING            COOLING          TOTAL"
1096 LPRINT TAB(30);QAUXH/1000;TAB(45);QAUXC/1000;TAB(65);(QAUXH-QAUXC)
1097 LPRINT TAB(30);QAUXH1/1000;TAB(45);QAUXC1/1000;TAB(65);(QAUXH1-QAUXC
1100 PRINT AC;TAB(5);TTC;TAB(10);TC;TAB(15);QAUXH/1000;TAB(25);QAUXC/1000
1105 PRINT TAB(15);QAUXH1/1000;TAB(25);QAUXC1/1000
1110 ETAST=0:QAUXC=0:QAUXH=0:QAUXH1=0:QAUXC1=0
```

```
1120 NEXT Y
1180 PRINT"WOULD YOU LIKE ANOTHER RUN(1 YES,0 NO)":INPUT  RI
1190 IF RI=1 THEN 500
1200 END
5000 QEX=UA*NS*N1(J)*(TI(J)-TC)
5010 IF QEX>QT(J) THEN QAB=QT(J):GOTO 5030
5020 QAB=QT(J)-QEX
5030 ABCS=QAB/QT(J)
5040 QS=(1-ABCS)*QT(J)
5050 IF QS=0 THEN F1=1:GOTO 5060
5055 F1=(1-QL(J)/QS)
5060 EFF1=1-F1*ETAS(J)
5065 IF QAUX(J)>0 THEN QAUX1=QAUX(J):GOTO 5080
5070 QAUX1=QL(J)-EFF1*QS
5080 TNH1=TA(J)+(QS+QI(J))/(UA*NS*N1(J))
5090 TI1=TNH1+(QAUX1/QL(J))*(TC-TA(J))
5095 IF TI1<TR(J) THEN TI1=TR(J)
5096 IF QAUX1>0 THEN QAUXH1=QAUXH1+QAUX1
5097 IF QAUX1<0 THEN QAUXC1=QAUXC1+QAUX1
5100 RETURN
```